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(P. G. MORGAN, Director.)

BULLETIN No. 23 (NEW SERIES).

GEOLOGY AND MINERAL RESOURCES

OF

WESTERN SOUTHLAND.

BY

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LETTER OF TRANSMITTAL.

GEOLOGICAL SURVEY OFFICE,
Wellington, 30th June, 1921.

SIR,—

I have the honour to transmit herewith Bulletin No. 23 (New Series) of the Geological Survey Branch of the Mines Department. This bulletin is entitled "Geology and Mineral Resources of Western Southland," and was written by Professor James Park, F.G.S., F.N.Z.Inst., as the result of field-work during the summer of 1919–20. The survey was undertaken in accordance with an arrangement between the Mines Department, the University of Otago, and Professor Park, whereby the services of the latter were given gratuitously and field expenses were paid by the Mines Department.

The bulletin contains 88 pages of letterpress, together with eight plates, seven text-figures, and two maps. It gives special attention to the Nightcaps–Ohai coalfield and its probable extension into the Waiau Valley, as well as to the occurrence of brick and pottery clays, and of limestones and marls suitable for the manufacture of Portland cement. A suggestion is also made that petroleum and natural gas may exist in certain parts of Southland.

I have the honour to be,
Sir,
Your obedient servant,
P. G. MORGAN,
Director, New Zealand Geological Survey.

The Hon. G. J. Anderson,
Minister of Mines, Wellington.

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THE GEOLOGY AND MINERAL RESOURCES OF WESTERN SOUTHLAND.

CHAPTER I.

GENERAL INFORMATION.

INTRODUCTION.

The area dealt with in this report lies to the west of the Takitimu Mountains, and includes the Waiau Valley and the country lying immediately to the westward of the chain of lakes drained by the Waiau River. A detailed examination was made of the Nighteaps, Wairio, and Ohai coal-fields with the view of tracing the relationship existing between the coal-measures of these areas and the Tertiary strata of the Waiau Valley. The western limits of the potential coal-bearing Tertiary rocks were defined from Port Craig, on the south-west side of Te Waewae Bay, northward to Blue Cliff, Lake Hauroto, Lake Monowai, Lake Manapouri, and the upper end of Lake Te Anau. The middle and lower parts of the Waiau Valley, and the area extending from Lake Monowai southward to Lake Hauroto and Port Craig, had previously not been geologically examined. And, except the reconnaissance survey of the country lying east of Lake Te Anau by Professor S. H. Cox in 1878 and the work of Mr. R. A. Farquharson at Round Hill in 1910, the western part of Southland has received little attention from New Zealand geologists.

SCOPE OF WORK.

The present examination was intended to be, in a measure, supplementary to the electrification scheme recently initiated by the Southland Electrification Board. Special attention was devoted to the probable extension of the Nighteaps and Ohai coal-measures into the Waiau Valley, and to the occurrence of brick and pottery clays and of limestones and marls suitable for the manufacture of Portland cement.

The research carried out by the author revealed the existence of large deposits of valuable clays, and of limestones and marls from which cement of good quality may be manufactured. It seems more than probable that cement-making will eventually develop into a flourishing Southland industry, the early stages of which will be stimulated by the demands of the electrification scheme.

A considerable area of good brown coal exists in the Ohai basin, and potential coal-bearing areas occur in the Waiau Valley. A seam of hard brown coal was discovered on the eastern shore of Lake Te Anau; and pieces of coal that may lead to important discoveries were found on the west side of that lake.

CLIMATE AND RAINFALL.

The region covered by this report possesses two distinct types of climate—namely, that of the Waiau Valley and foothills, and that of the highlands.

In the Waiau Valley during the summer and spring months the temperature ranges from 52° F. to 84° F. in the shade, and in winter from a few degrees below 32° F. to 63° F. Generally the summer is warm and genial, and the winter cold and bracing. The rainfall ranges from 32 in. to 44 in. a year, and is most abundant in winter and spring, and least from the end of January till the middle of May.

During winter and early spring the tops of the Takitimu Mountains and of the ranges on the west side of the Waiau Valley are snow-covered; and at times the snow may creep down to the flats in the upper part of the main valley, but as a rule it disappears in a few hours, or a few days at the utmost. Years of exceptional dryness and excessive rainfall are known, but European occupation has been so short that probably the driest and wettest seasons have not yet been recorded.

Concerning the rainfall and snowfall on the Takitimu Mountains and the ranges of the alpine divide nothing whatever is known. But if we may judge by the rainfall records of other mountain-chains in the same latitude we shall probably not be far wrong if we place the rainfall in this part of the highlands of south-west Southland somewhere between 92 in. and 154 in. a year.

LAKES.

In a mountain region so profoundly faulted and glaciated it is not surprising to find many lakes, tarns, and lagoons.

Lake Te Anau is the largest lake in the South Island. Its length is thirty-eight miles, and its breadth ranges from one to six miles. The three western arms or fiords of the lake range from ten to eighteen miles in length and from one to three miles in breadth. The area of the lake is 132 square miles. The mean surface-level is 679 ft. above sea-level, and the greatest depth, which occurs near the entrance to the North Fiord, is 806 ft., or 127 ft. below sea-level.

Lake Manapouri* is irregular in shape, being deeply indented by bays and fiord-like arms. Its surface is broken by many small islands; and dense forest vegetation clothes both the islands and surrounding mainland down to the water's edge. Manapouri may justly claim to be the most beautiful and picturesque lake in New Zealand. The surface of the lake is 599 ft. above the sea. The greatest depth, which is found about a mile west of Pomona Island and immediately opposite the entrance of the South Arm, is 1,458 ft., or 859 ft. below sea-level. The length of the lake is eighteen miles, the greatest breadth six miles, and the area about fifty square miles.

Lake Monowai† lies 676 ft. above the sea. It is about fourteen miles in length, and has an average breadth of three-quarters of a mile, its surface area being about eleven square miles. In shape it resembles a well-made boomerang; and it lies in a narrow cañon, on both sides of which the mountains rise abruptly from the water's edge. The depth of the lake is unknown, but the steepness of the bounding walls would indicate a considerable depth. At the lower end there is a glacial moraine through which the present outlet has been excavated by the Monowai River, which drains the lake. To what depth the lake is moraine-contained is not known. The morainic matter rests on Tertiary marine clays, which are well exposed on the banks of the Borland River

* Keith Lucas: A Bathymetrical Survey of the Lakes of New Zealand, *The Geogr. Jour.*, vol. 23, pp. 755–59, 1904, with map.

† This lake was named by James McKerrow, F.R.G.S. The name is not pure Maori, as many suppose, but a hybrid derived from the Greek *monos* = alone, and Maori *wai* = water. From these McKerrow derived Monowai = lonely water.

PLATE I.

View looking across Lake Te Anau towards Middle Fiord.

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near Monowai Flat. Probably the depth of the glacial drift is not great. The steep even mountain-wall on the south side of the lake, unbroken by spurs or deep watercourses, is an evidence of intense Pleistocene glacial erosion.

Lake Monowai lies in a long narrow basin, hemmed in on all sides by steep mountains. As a consequence its restricted watershed is fed only by small torrential streams with short courses.

Lake Hauroko* (or, as more correctly designated on old maps, Lake Hauroto) is separated from Lake Monowai by the Kaherekoau Mountains on the north side and from Lake Poteriteri by the Princess Mountains on the west side. It lies 514 ft. above the sea. Its length is about twenty-two miles, and mean breadth a little under a mile and a half, giving a surface area of some thirty-two miles. St. Mary's Bay, with an area of about six square miles, is shallow, but of the depth of other parts nothing is known at present. Except at St. Mary's Bay the lake is bounded by steep cañon-like walls. It runs back almost to the heart of the main divide, at one place reaching within twelve miles of the head of Dusky Sound. Lake Hauroto is a typical fresh-water fiord occupying a depression in the floor of a profound mountain cañon. At present the lake is drained by the Wairaurahiri River, which flows south and enters the sea about five miles west of Sandhill Point. This rapid river falls 514 ft. in its course of twenty-four miles, and for most of that distance runs in a rugged rocky gorge.

In glacial times Lake Hauroto belonged to the Waiau River system, and was drained by the Lillburn, which joins the Waiau two miles above Clifden. The Hauroto glacier, before its final retreat, piled up its terminal moraine on the east side of St. Mary's Bay to a height of several hundred feet, thereby completely blocking up the Lillburn outlet. At the present time the Lillburn rises about two miles from Lake Hauroto.

After the blocking of the Lillburn outlet the lake found a new outlet by way of the Waikoau River, which flows into the sea near Blue Cliff, on Te Waewae Bay. Subsequently, when the present outlet was formed, drainage of the lake by the Waikoau outlet ceased. At the present time the source of the north branch of the Waikoau River reaches within three-quarters of a mile of the lake. The ground between the lake and the Waikoau is low and swampy; and since the distance to the sea by the Waikoau is much less than by the Wairaurahiri, which now drains the lake, we may surmise that the abandonment of the shorter for the longer route was caused by the former being blocked by an accumulation of ice on the south side of St. Mary's Bay.

Lake Hauroto is fed at its upper end by the Hay River coming in from the north-west, and the Templeton River coming in from the north, both of which are large streams. Many mountain-torrents enter the lake from both the Princess and Kaherekoau mountains, but, except the Caroline Burn, which drains the east side of the Princess Mountains, all are small and unimportant, though their aggregate flow is considerable.

Lake Poteriteri lies from three and a half to ten miles west of Lake Hauroto. Its surface is 94 ft. above sea-level, or 420 ft. lower than that of Lake Hauroto. The length of the lake is seventeen miles, and its general trend almost due north and south. The breadth for the most part ranges from three-quarters of a mile to a mile. Only in a length of four short miles, near the lower end, does the breadth widen to a mile and a quarter. The lake is drained by the rapid-flowing Waitutu River, whose course from the outlet to the sea is some eight miles long.

The lake is fed by many small streams, and by the Princess Burn, which enters the head of the lake, and by the Charlton Burn, which drains Lake Mouat. The Princess Burn heads back almost to the source of the Hay River, while the Charlton Burn drains the eastern slopes of the Cameron Mountains.

Lake Hakapoua lies six miles west of the south end of Lake Poteriteri. It is a tidal sheet of water four miles long and a mile wide. This lake drains a relatively large area, and is fed

* According to the *Maori Dictionary* of Archdeacon William Williams, D.C.L. (2nd ed., London, 1852), and Tregear's *Maori-Polynesian Comparative Dictionary* (Wellington, 1891), *roko* is not a Maori or Polynesian word. In Maori *roto* is the only word for lake. Hauroko is undoubtedly a corruption of Hauroto.

by the Big Burn, a considerable stream. It is drained by the Big River, or Patupo, which is three miles long.

The general trend of lakes Hakapoua, Poteriteri, and Hauroto, and of the western half of Lake Monowai, is north and south. And it is not a little singular that in passing from north-east to south-west these lakes overlap one another in echelon.

RIVERS.

The Waiau, with its chain of lakes and tributary streams, is the dominant river-system of western Southland, and ranks among the great rivers of New Zealand. From the main divide on the west Lake Te Anau is fed by many large rivers, among them the Clinton River, which enters the lake near Glade House. Farther south the Glaisnock River flows into the head of the North Arm. It drains a large area lying between the Franklin and Stuart mountains, and its headwaters reach back within two miles of Bligh Sound. The streams draining into the north-west and south-west arms of the Middle Fiord are small, except when swollen by heavy rains or melting snow. The country at the head of the South Fiord is drained by the Esk Burn and Gorge Burn. The former rises at Lake Duncan, which lies only four miles from the head of Nancy Sound. In its course lie Lake Te Au and Lake Hilda, both of which occupy rock-basins. Gorge Burn drains seven small mountain-lakes, the largest of which, Lake Hall, lies at an altitude of 2,625 ft. above the sea, and is less than two miles from the Gear Arm of Bradshaw Sound.

The country lying on the east side of Lake Te Anau is drained by the Eglinton River, which rises on the western slopes of the Livingstone Mountains, and by the Upukerora River, whose headwaters rise on the southern slopes of Te Anau Hill.

The only large stream flowing into Lake Manapouri is the Grebe River, which rises at Lake Green, near Lake Monowai, and runs north, eventually flowing into the head of the South Arm.

The largest tributary of the Waiau River is the Mararoa River, which joins the Waiau seven miles below the outlet of Lake Manapouri. The Mararoa River rises in the high country lying between the Livingstone and Eyre mountains. One branch of this river reaches within six miles of Lake Wakatipu. Lower down the Waiau Valley come in the Borland Burn, opposite Blackmount; the Monowai River, from Lake Monowai; and the Lillburn, which heads nearly back to Lake Hauroto. The only large stream coming in from the east is the Wairaki River, which drains the southern slopes of the Takitimu Mountains. During the wet season the Orawia River, which rises on the west side of the Longwood Range, becomes swollen to the size of a small river. Normally it is a very small stream.

FAUNA.

Mammals.

Apparently the only form of indigenous mammalian life represented in this district is the long-tailed bat (*Chalinolobus morio*), which is not uncommon in the middle and lower parts of the Waiau Valley.

Bird-life.*

The indigenous bird-life is well represented, and some forms that are generally thought to be rare are fairly numerous. On the other hand, some species that were common on the eastern side of the main divide thirty years ago are exceedingly rare or altogether extinct. Nothing was seen of the New Zealand quail, fern-bird, robin, or South Island thrush, though some of them may still survive in secluded places.†

* The scientific names quoted are founded (with some modifications as respect trinomial names) upon Matthews and Iredale's "Reference List" as given by Professor W. B. Benham in *Trans. N.Z. Inst.*, vol. 46, pp. 188–204, 1914.

† A pair of robins was seen by the author in the Eglinton Valley near Lake Gunn on 14th February, 1921.

PLATE II.

OUTLET OF LAKE MANAPOURI, LOOKING TOWARDS KEPLER MOUNTAINS.

[To face p. 4

The South Island tomtit (*Myiomoira macrocephala*) was seen as solitary pairs at Lake Hauroto, Blue Cliff, Manapouri, and Clinton Valley, at elevations ranging from sea-level to 2,500 ft. above the sea.

The ground-lark, or pihoihoi (*Anthus novæseelandiæ*), is fairly common in the open parts of the Waiau Valley between the mouth of the Wairaki River and Blackmount.

The South Island grey warbler, or riroriro (*Maorigerygone igata* Q. & G.), is common everywhere in the plantations around homesteads, and in the forest up to 2,500 ft. above the sea. At one time a shy solitude-loving bird, the riroriro seems to be adapting itself to the new environment created by the advance of settlement.

The tui (*Prosthemadera novæseelandiæ* Gmelin) frequents the forest lands in the lower part of the Waiau Valley and in the country between Tuatapere and Blue Cliff. On no occasion was it seen at an altitude exceeding 1,000 ft. above the sea. It is rare in beech forests, even when not uncommon in the neighbouring mixed bush.

The bell-bird, or makomako (*Anthornis melanura*), whose deep, melodious, bell-like notes are famed in Maori song, is common not only in Southland but throughout the whole of Otago. A quarter of a century ago it became so rare that it seemed on the eve of extinction. In the past ten years it has reappeared in considerable numbers not only in the native forests, but in orchards and plantations. This wonderful songster is usually seen in pairs in winter and the breeding season. Early in March seven of these birds were seen together by the author near Sandy Point Hut at Milford Sound. They were probably members of the same family. Thirty years ago the bell-bird was excessively shy, and as a rule poured out its melody from the leafy shelter of some high tree. The present-day bird is less timid, and often ventures into scantily clad trees standing out in the open. Of this new habit examples could be multiplied in plenty. In April, 1918, the bell-bird was one of the commonest of the indigenous birds around Hampden, and generally showed as little concern at the approach of man as the imported blackbird. On one occasion a full-grown bird alighted on the dead limb of a solitary tree overhanging the road, near the stone bridge at Gillies's homestead, and with full throat poured out its wonderful contralto not more than four yards from the author and his wife. The seven seen at Milford Sound flitted among the low branches of the New Zealand fuchsia without fear or concern. At the time of writing (April, 1920) a solitary bell-bird sings almost daily in a walnut-tree close to the porch of the author's house at Otago University, Dunedin.

The brown creeper (*Finschia novæseelandiæ*) is sometimes seen in the forest between Lake Monowai and Lake Manapouri. In February, 1918, the writer saw a pair in the bush on the south-west slope of Mount Earnslaw at an altitude of 3,000 ft. above the sea.

The white-eye (*Zosterops lateralis tasmanica* Mathews)—by Europeans sometimes called the silver-eye or blight-bird—was seen at Clifden in February. This is an Australian bird that was unknown in New Zealand before 1856. Its Maori name "tauhou," meaning "stranger," refers to its recent arrival in New Zealand. The white-eye appears about Dunedin in spring in companies of half a score or more.

The kingfisher (*Sauropatis sanctus forsteri* Mathews and Iredale), once so common on the banks of streams at all altitudes below 1,000 ft., is seldom seen in the Waiau Valley.

The yellowhead (*Mohoua ochrocephala* Gmelin) is occasionally met with in the forest country around Lake Monowai. A small flock of eight was seen early in March near the upper end of Lake Ada in the Arthur Valley.

Early in February a single representative of the long-tailed cuckoo (*Urodynamis taitensis* Sparrman), the "kohoperoa" of the Maori, was seen at Lake Hauroto. It flitted around the camp-fire at dusk, its approach being heralded by a plaintive call. The shining cuckoo (*Lamprococcyx lucidus* Gmelin) was not met with, though it is known to frequent the same forest.

The morepork, or ruru (*Spiloglaux novæseelandiæ* Gmelin), is occasionally heard on the edge of the forest up to a height of 7,000 ft. above the sea.

The kaka (*Nestor meridionalis*) is common everywhere in the forest country on the west side of the Waiau River at all altitudes up to 2,000 ft. above the sea. Every evening at sundown they began circling around the Sutherland Falls and Quintin huts; and almost every night their harsh calls could be heard up till midnight, high up on the wooded slopes of the main divide.

The kea (*Nestor notabilis* Gould) is seen at all altitudes above 2,000 ft., but its favourite haunt during the daytime is the grassy mountain-slope above the bush-line. At night it perches on the limbs of dead trees at the upper edge of the forest, somewhere about 3,000 ft. above the sea. In stormy weather the kea will occasionally descend to the floor of the mountain-valleys, and perch at an altitude of 1,000 ft., or somewhat less, above the sea.

In his travels in this and Lake Wakatipu regions the author was unable to gather from the runholders, or the shepherds, any evidence that would substantiate the charge of sheep-killing laid at the door of this bird. In the summer of 1880–81, while assisting Mr. Alexander McKay in a geological reconnaissance of the Ohau, Wanaka, and Matukituki country, diligent inquiry among the shepherds failed to disclose any satisfactory evidence of the rumours then beginning to find their way into the newspapers which credited the kea with sheep-killing. In every case the evidence was found by the author to rest on the statement of some shepherd who, on being interviewed, invariably admitted that his charge against the kea was based on statements made to him by some other shepherd. In every case that was investigated the bird was found guilty on second-hand evidence alone. Though keas are plentiful in the Tasman Valley, the guides at Mount Cook Hermitage assert without hesitation that the kea is no sheep-killer in that region. Possibly there may be parts of the Canterbury mountains where the kea has developed an appetite for mutton, but in every case the evidence should be sifted by shrewd cross-examination. Generally, New Zealand scientists consider that the charge against the kea has not been proven. On the other hand, the runholders are divided in their opinion; and, whether guilty or not guilty, the law decrees the kea an outlaw that may be destroyed at sight. The subject is surely one that ought to engage the attention of some unprejudiced investigator.*

Parrakeets (*Cyanorhamphus*), once so common on the fringe of all our great forests, are now relatively rare. Three of the yellow-fronted species were met with at Lake Hauroto. Parrakeets were heard, but not seen, in the lower Clinton Valley. They probably belonged to the red-fronted or yellow-fronted species, both of which are reported to survive in the Te Anau country.

The beautiful wood-pigeon (*Hemiphaga novæseelandiæ* Gmelin) is abundant in all the lowland forests lying west of the Waiau River. At Blackmount homestead, where indigenous birds find themselves in a protecting sanctuary, the native pigeon is a frequent visitor, and in early summer takes a heavy toll of the cherries growing in the orchard. By the use of a ladder the author made a close inspection of two pigeons roosting in a large cherry-tree. They were so tame that they viewed his approach with unconcern till within three yards of them, when they moved their heads uneasily, but immediately settled themselves in an attitude of confidence on finding that no nearer approach was attempted.

It was a pleasant surprise to find that the dark-brown woodhen, or weka (*Gallirallus brachypterus* Lafresnaye), which for two or three decades seemed in danger of extinction, now abounds in all the Fiordland forest country. Every camping-place was immediately adopted by a pair of birds that fiercely resented trespass by all other members of the tribe. The grunting sounds, shrill calls, domestic squabbles, and impudent thieving of the weka were reminiscent of camping-days in the alpine regions of Otago forty years ago.

The swamp-hen, or pukeko (*Porphyrio melanonotus*), whose brilliant colouring seems to fit in badly with its usual haunts, is rare.

During the progress of the survey diligent inquiry was made as to the probable existence of the large flightless rail, the takahe (*Mantellornis hochstetteri*), in the Hauroto, Monowai, Te Anau country, but without finding any evidence that would lead to the belief that this beautiful bird was still alive. If not already extinct it must be excessively rare.

The boom of the bittern (*Botaurus pœciloptilus*) was heard only once in the neighbourhood of Lake Hauroto.

The white heron, or kotuku (*Herodias alba maoriana* Mathews and Iredale), never common since European settlement began, is now exceedingly rare. A single representative appeared

* See G. R. Marriner's papers in *Trans. N.Z. Inst.*, vols. 39 and 40, 1907, 1908.

in different parts of the Taieri Plain during the spring of 1919, but no trace of this beautiful bird was seen in the Waiau country.

The black shag (*Phalacrocorax carbo*) is abundant at Lake Hauroto, Lake Monowai, in parts of Lake Manapouri and Lake Te Anau, and at Milford Sound.

The crested grebe (*Podiceps cristatus*) is common at Lake Hauroto, but was not seen at Lake Manapouri or Lake Te Anau.

The paradise duck, or putangitangi (*Casarca variegata*), is more than holding its own everywhere in the South Island. In south-west Southland and western Otago it is numerous on the grassy flats of all the larger rivers. At Lake Ada they were present in scores early in March of the present year. While at the Quintin huts the writer frequently heard the "honk" of this beautiful bird after dark, as in small coveys it flew up the Arthur Valley on its way across McKinnon's Pass to Lake Te Anau.

The blue duck, or whio (*Hymenolaimus malacorhynchos*), is met with in the bed of almost every mountain-torrent. The shorter streams seem to be in possession of a solitary pair. The whio has a slaty-blue colour that often harmonizes perfectly with its rocky environment, and but for its plaintive call it might easily be overlooked. This bird seems to be as plentiful as it was forty years ago.

The grey duck, or parera (*Anas superciliosa*), and the grey teal (*Nettion castaneum*) are found throughout the whole of the Waiau and Milford Sound country, the former being plentiful. These birds range from New Zealand to Australia and Java, and are in little danger of extermination, notwithstanding the great slaughter during the shooting season.

The black teal, or pupango (*Fuligula novæseelandiæ*), was seen at Lake Hauroto and Lake Ada, but is not common.

The kiwi, the sole survivor of New Zealand's wingless birds—a quaint survival that in its structure appears to represent several different orders—is now scarce even in the unfrequented fastnesses of the main divide. The peculiar whistling cry of the kiwi was heard only on two occasions, once near the Sutherland Falls and once on the wooded mountain-slope immediately north of the Quintin huts.

The green mountain-parrot, or kakapo (*Strigops habroptilus*), once so common on the scrub and grass country above 3,000 ft., is now rare. Well-beaten tracks made by this bird traversed the upland grass-lands in all directions a few decades ago, but are now rarely seen.

The harrier-hawk, or kahu (*Circus gouldi*), is common in all the open country. The sparrow-hawk, or karewarewa (*Nesierax australis*), though apparently holding its own, is by no means plentiful. Two full-grown specimens were seen near Lake Monowai early in March.

In the month of January the white-fronted tern (*Sterna striata*), the pied stilt (*Himantopus leucocephalus alba*), the redbill (*Hæmatopus niger unicolor*), and the dotterel (*Pluviorhynchus obscurus*) were met with on the coast between Orepuki and Mussel Beach, on the south side of Te Waewae Bay.

FLORA.

It is now recognized that the philosophical study of the development of plant and animal life is more important than the mere collecting, technical description, and classifying of species. At most times cynical, Carlyle scoffed with perhaps unnecessary fierceness at all work of this kind, which he described as the progeny of methodists possessed of the pigeon-hole type of mind. Herbert Spencer, himself an ardent evolutionist and of calmer judgment than Carlyle, was willing to admit that the counting of the scales on a fish, the segments of a crustacean, the ribs of a mollusc, or the petals of a flower might possess a certain value if carried out with discrimination as to the limits of variability. As these limits were themselves variable, he insisted that such mechanical work was more often a hindrance than a help to science. It is perhaps comforting to find that he extolled the work of William Smith and of the geologists who endeavoured to unravel the earth's history by patient mapping and the record of rock-relationships. There is no doubt that in their vehement denunciation of what they called "mechanical intellectuality" both Carlyle and Spencer did an injustice to scientists engaged in descriptive work. At the same time Spencer's advocacy of genetic as opposed to morphological methods of investigation powerfully impressed contemporary Continental workers.

Dr. L Cockayne, F.R.S., a close follower of the Continental school of ecologists, was the first in New Zealand to employ genetic methods of research founded on a realization of the need of a closer scrutiny of the progressive changes arising from adaptation to environment and plant-assemblages than was deemed necessary by early botanists. To give a surer basis for diagnosis in mineral occurrence, the morphological study of ore-deposits has long given place to the genetic. And it is certain that if lists of plants, with their technical descriptions, were supplemented with notes on the conditions of rainfall and drainage, situation of station in respect of prevailing winds and sunshine, character of rock-formation and soil, a clue would be found as to the determining conditions of plant-morphology and plant-paragenesis.

In a plant-assemblage the different units must be subject to, and approve of, the same dominant influences, of which plant-food, station, and drainage are perhaps the most important. But even in the same station certain plants appear to possess the peculiar selective power of abstracting from the soil some mineral constituent that has become necessary to its growth and well-being. The lead-plant (*Amorpha canescens*) is abundant in Michigan, Wisconsin, and Illinois. It is a low shrub covered with a hoary down, and is believed to flourish best in soil containing lead. The calamine pansy (*Viola calaminaria*) is peculiar to the calamine-bearing hills of Aix-la-Chapelle in Rhenish Prussia. Analysis has revealed the presence of zinc in the plant and in the ash. In Spain prospectors for phosphates are guided in their search by a creeping-plant called *Convolculus althæoides*, which is common on soils containing a high percentage of calcium phosphate.

If we admit biological continuity we must recognize that species as defined by naturalists are separated by purely artificial barriers. Hence the conception of immutable kinds must be accepted with great reservation. So long have we been familiar with the mechanical subdivision of organisms into genera and species that it is difficult to divest the mind of the fallacy that species are distinct kinds. But species cannot be created by verbal definition. As contended by Spencer, it is in the variation of the type that we see the differentiation that in countless thousands of years has produced the wider differences in plant and animal life. Probably all variation is the result of geological happenings, and of the climatic changes arising therefrom.

Plant-life not only arranges itself in ascending horizontal zones, but also in assemblages that are influenced by such factors as the wetness or dryness of the soil, salinity of the soil and atmosphere, composition of the rocks and resulting soil, conditions of soil and subsoil drainage, relative acidity or alkalinity of soil, plant-societies, light and shade, relative thermal conductivity of soil, prevailing winds and rainfall. Besides these outstanding conditions come the less known but not less important activities of nitrogen, silica, lime, and the influence of pathogenic bacteria. Moreover, there may be other minute but determining factors that have not yet been recognized. Among these last, selective absorption may not be the least. And as the appearance of new orders may arise from the development of a structure, extinction may result from the exaggeration of a structure or the removal of an inhibiting influence. Clearly the future of plant-physiology lies in the domain of biochemistry and ecology.

Several different plant-stations may exist in the same horizontal zone. Thus in the zone from sea-level up to 1,000 ft. we have coastal sand-dunes, salt-meadow lands and salt swamps, river-terraces, river-beds, and fresh-water swamps, each peopled by plants that have adapted themselves to their peculiar environment.

Many forms of plant-life, perhaps most, are unable to survive certain changes of condition. Examples of this could be multiplied by the score. The case of the common rush (*Juncus effusus*) is familiar to every farmer. This pest grows on wet undrained lands, and flourishes most luxuriantly when its roots are in contact with stagnant water that has become acid through the decomposition of decaying vegetation. As soon as the land is drained, so that the water is able to circulate in the subsoil, the rushes disappear automatically, being unable to live in soil containing a certain minimum amount of acidity. The same result is obtained by neutralizing the acidity by the unstinted application of lime, but the results are less permanent than those obtained by good drainage. The degrees of minimum acidity and alkalinity required by different fodder plants and cereals have yet to be investigated.

Many plants possess considerable powers of adaptability to changing conditions. Notable among New Zealand plants of this kind are the native heaths and brooms, which protect themselves in dry situations by diminishing the numbers and size of their leaves, or by discarding leaves altogether, thereby reducing the effective area from which the plant-water passes into the atmosphere as water-vapour.

The effect of a plentiful supply of moisture on the well-known wild-irishman (*Discaria toumatou*) is remarkable. On the dry river-terraces it is stunted, gnarled, bare of leaves, and covered with thorns ranging from 1 in. to 2 in. or more in length. Along the edges of the lakes its branches are covered with green leaves ½ in. long; and the thorns, though not altogether suppressed, are seldom over ¾ in. in length. In shaded moist valleys it sometimes grows to a tree 20 ft. high and 10 in. in diameter.

The botanical zones and subzones that may be distinguished in western Southland are: (1) The salt-meadows and salt-swamp zone; (2) the meadow zone, from sea-level up to 1,000 ft.; (3) the river-bed assemblage of plants; (4) the zone of mixed bush, from sea-level up to 1,200 ft.; (5) the forest zone, from 1,200 ft. up to 3,000 ft.; (6) the subalpine zone, from 3,000 ft. up to 3,500 ft.; (7) the alpine zone, from 3,500 ft. up to 6,000 ft.

The Salt-meadows and Salt-swamp Zone.

A common plant of the salt marshes is the reddish-brown rush-like oioi (*Leptocarpus simplex*). Though essentially maritime, it has been reported as occurring near hot springs at Rotorua and Tokaanu (Lake Taupo). Dr. Cockayne has recently, so he informs the writer, met with the oioi at Lake Manapouri. These exceptional occurrences are probably due to the existence of some of the peculiar conditions that make the sea-littoral the normal habitat of this plant. Its presence in the volcanic region of the interior of the North Island may arise from sodium and magnesium salts deposited in the swampy soil by certain hot springs, which are known to be rich in these constituents; but there are no hot springs at Lake Manapouri, and therefore we must search for the cause in some other direction. Below the screen of glacial drift at Lake Manapouri there lies a great thickness of marine Tertiary sandstones and clays. Now, incrustations of salt (sodium chloride with some magnesium chloride) are common at the outcrops of Tertiary clays in the Awatere Valley, Baton River, Upper Wanganui, and elsewhere in the Dominion, in all cases deposited where seepages of saline waters issue at the surface from cracks in the soft marine strata. Though no seepages of brine can be seen at Lake Manapouri, it is not improbable that such do occur, creating in favourable situations the salt-marsh conditions that attract the oioi. The occurrence of this plant so far inland is of sufficient importance to warrant careful investigation.

Besides the oioi, other forms met with in the salt meadows near the sea are the pale-green sedge *Carex litorosa*, the densely tufted *Juncus pallidus*, the small grass *Atropis stricta*, and the daisy-like *Cotula dioica*. This last, though most abundant near the sea, curiously enough ranges up to 3,000 ft. above sea-level, a result perhaps of certain geological happenings.

The Meadow Zone, from Sea-level up to 1,000 ft.

This zone lies mainly within the tract of cultivated lands or of lands devoted to pastoral purposes. The greater part of the open flats along the Waiau River have been ploughed, while all the open downs n the valley of that river have been swept by fire so often that most of the native vegetation has become exterminated. Conspicuous among the survivors are the tussock-grasses (*Poa cæspitosa* and *Festuca rubra*), the graceful toetoe (*Arundo conspicua*), and the New Zealand flax (*Phormium tenax*). In wet ground and in undrained swamps the wiry niggerhead (*Carex secta*) is abundant; and in recently drained land its dead stumps afford shelter for higher forms of vegetation.

In the scrub-covered patches we find near the sea *Olearia angustifolia*. Behind the first fringe *Olearia Colensoi* and *Senecio rotundifolius* are plentiful. On dry, stony, wind-swept places the heath *Dracophyllum longifolium* has established itself at an altitude far below its usual habitat. The poisonous plant tutu (*Coriaria ruscifolia*) is common along the river-banks and along the sides of bush tracks. Isolated trees or clumps of kowhai (*Sophora tetraptera*); of the cabbage-tree, or ti of the Maori (*Cordyline australis*); and the beautiful ribbonwood (*Plagianthus betulinus*) are common on the river-flats of the Waiau Valley above Clifden. On the gravelly morainic river-flats between the Waiau River and Lake Monowai the tea-tree, or manuka (*Leptospermum scoparium*), is abundant, and in places forms a dense almost impenetrable scrub. Matted clumps of *Coprosma* of several species abound on the dry terraces.

River-bed Assemblage of Plants.

The Waiau River for the greater part of its course runs in a channel bounded by steep well-defined banks. For a great part of the year the river occupies almost the whole width of its channel, with the result that the assemblage of river-bed plants frequently met with in other parts of Southland is but sparingly represented. On the silt-banks in the upper reaches of the Waiau River the subalpine buttercup (*Ranunculus Godleyanus*) and mountain-tutu (*Coriaria angustissima*) are often met with. On the silt-formed banks of clear slow-running rivulets is sometimes seen the beautiful native musk (*Mimulus radicans*), ranging up to 1,000 ft. above the sea.

The Zone of Mixed Bush, from Sea-level up to 1,200 ft.

Among the common forest-trees of this zone are the red-pine or rimu (*Dacrydium cupressinum*), miro (*Podocarpus ferrugineus*), matai (*P. spicatus*), totara (*P. totara*), southern rata (*Metrosideros lucida*), kamahi or so-called red-birch (*Weinmannia racemosa*), New Zealand beeches (*Nothofagus fusca, N. Solanderi*, and *N. Menziesii*), and kawhaka or cedar (*Librocedrus Bidwillii*).

Between the Mararoa River and Lake Manapouri the main road to Te Anau passes across a stony, wind-swept, moraine-formed desert dotted with small clumps of the subalpine bog-pine of New Zealand (*Dacrydium Bidwillii*), the effect of which in their desert setting is weirdly picturesque. The surface conditions are suggestive of arid rather than bog conditions, and we can only suppose that these dwarf pines are clinging to the site of a bog that has become drained in comparatively recent years.

Of the beeches, *Nothofagus fusca* does not rise above this zone. Generally it flourishes in Southland and western Otago between 400 ft. and 1,000 ft. above the sea. It grows into stately trees, and is never met with except on alluvial river-flats or glacial drift. In no case was it found on rocky spurs or ridges. Many fine samples occur near Lake Hauroto and in the lower end of the Clinton Valley.

Tanekaha, the celery or turpentine pine of the settlers (*Phyllocladus trichomanoides*), is common on the swampy morainic flats between the Lillburn River and Lake Hauroto. On the forest fringe we meet the green-leaved broadleaf (*Griselinia littoralis*); lancewood, or horoeka (*Pseudopanax crassifolium*); makomako (*Aristotelia racemosa*); ribbonwood (*Plagianthus betulinus*); white-maple (*Carpodetus serratus*); pepper-tree (*Drimys colorata*); tea-tree, or manuka (*Leptospermum scoparium*); the tree-fuchsia, or kotukutuku (*Fuchsia excorticata*); koromiko (*Veronica salicifolia*); akeake (*Olearia avicenniæfolia*), found up to 2,500 ft.; five-finger, or patete (*Schefflera digitata*), which ascends to 2,500 ft. in Southland, and is the only native species of this genus in New Zealand; hupiro (*Coprosma fœtidissima*); bush-lawyer (*Rubus australis*); supplejack (*Rhipogonum scandens*); and clematis (*Clematis indivisa*).

Among the woody mistletoes none are more plentiful than the scarlet *Loranthus Colensoi*, the yellowish-red *L. Fieldii*, and orange-yellow *L. flavidus*; the first and last often parasitic on the beeches up to 2,000 ft.

The forest of mixed bush between Blue Cliff and Mussel Beach (Port Craig) contains ferns in great variety, the genera *Asplenium*, *Lomaria*, and *Polypodium* being well represented. The feather-like *Todea hymenophylloides* is plentiful in the Arthur Valley, but the Prince of Wales's feather (*T. superba*) was not seen. The peculiar kidney-fern (*Trichomanes reniforme*) is not uncommon in damp places on both sides of the main divide.

It is noticeable that most ferns prefer the shade of a forest, deep ravine, or steep cliff. They seem to thrive best where there is an abundant rainfall, perfect drainage, and freedom from intense frost. Among the few ferns that grow in the stagnant water of swamps is the umbrella-fern, or tapuwaekotuku (*Gleichenia dicarpa*). Lycopodiums, the bog-moss (*Sphagnum*), and numerous other mosses are everywhere plentiful in the forests and bogs of south-west Southland.

The Forest Zone, from 1,200 ft. up to 3,000 ft.

Above 1,200 ft. the forest changes greatly in character. Through the absence of undergrowth it becomes more open; and, while ferns are less numerous, the forest-floor is still carpeted with lycopodiums and mosses. The commonest trees are the beeches *Nothofagus Solanderi* and *N. Menziesii*, both of which are found growing on alluvial flats and rocky slopes. Next in abundance comes the southern rata (*Metrosideros lucida*), whose favourite haunts are the sides of gorges and the rocky slopes of steep ridges. The broadleaf (*Griselinia littoralis*), usually gnarled and stunted, grows up to 1,500 ft. or more, but is not abundant. Kawhaka, or cedar (*Libocedrus Bidwillii*), is common in wet places, and the heath (*Dracophyllum longifolium*) is abundant in the upper part of the river-valleys. The ribbonwood, or manatu (*Plagianthus betulinus*), is met with in great abundance in the mountain-valleys up to 1,500 ft. above the sea.

The Subalpine Zone, from 3,000 ft. up to 3,500 ft.

At about 3,000 ft., or 3,200 ft. at the most, we reach the upper limit of the forest; and from this upward to about 3,500 ft. we have the zone of subalpine scrub, fringed at its outer edge with a luxuriant belt of tussock (*Danthonia Raoulii*). Among the shrubs were noted *Coprosma parviflora*, *C. cuneata*, *C. repens*, *C. serrulata*, *Olearia moschata*, *Senecio bellidioides*, *S. Haastii*, *Carmichaelia Monroi*, *C. corymbosa*, *Panax Colensoi*, *Veronica macrantha*, *Podocarpus nivalis*, *Phyllocladus alpinus*, *Drachophyllum Menziesii*, and *D. strictum*.

The Alpine Zone, from 3,500 ft. up to 6,000 ft.

Above the scrub belt we meet the alpine meadowland, the habitat of many beautiful mountain-plants. Conspicuous among these are the celmisias, with their daisy heads rimmed with fine white petals; the mountain-buttercups, gentians, mat-like raoulias, the mountain-carrot, mountain-tutu, ourisias, violas, gaultherias, euphrasias, and many grasses. The xerophytes, or plants provided with special contrivances to check transpiration, are represented by the whip-cord veronicas, usually met with on dry stony slopes. Some of the more common forms identified in the alpine zone on the west side of the divide were *Ranunculus Lyallii*, *R. Buchanani*, *R. tenuicaulis*, *Viola Cunninghamii*, *Coriaria thymifolia*, *Epilobium confertifolium*, *Aciphylla Lyallii*, *Celmisia discolor*, *C. Haastii*, *C. coriacea*, *C. Lyallii*, *C. laricifolia*, *C. sessiliflora*, *C. glandulosa*, *C. ramulosa*, *Raoulia subulata*, *R. Hectori*, *Gentiana montana*, *Myosotis pulvinaris*, *Veronica Hectori*, *Ourisia Colensoi*, *O. sessiliflora*, *Euphrasia antarctica*, *E. revoluta*, *Astelia linearis*, *Carex Petriei*, *Danthonia flavescens*, *Deschampsia tenella*, *Poa foliosa*, and *P. Colensoi*, the latter the blue-grass of the settlers. Everywhere above the scrub-line the dominant grass is the fescue-tussock (*Festuca novæ-zealandiæ*).

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The splendid maps published by the Lands and Survey Department of New Zealand form the groundwork on which the geological maps accompanying this report are based.

The records of the strata passed through in the boreholes drilled in the Ohai Valley are published by permission of Mr. A. W. Rodger, for whom the drilling was carried out in 1916.

Some of the chemical analyses quoted in this report were made at Otago University, but, except where otherwise stated in the text, all the analyses that are now published were made in the Dominion Laboratory, Wellington, by Dr. J. S. Maclaurin and his staff. Dr. Maclaurin's report on the clays of west Southland is a valuable contribution to the economic geology of the Dominion.

CHAPTER II.

GEOLOGICAL STRUCTURE AND PHYSIOGRAPHY.

GENERAL GEOLOGICAL STRUCTURE.

Along the seaward side of the West Coast Sounds there is a belt of metamorphic rocks that strikes about north-south, and dips to the west. The lower division of these rocks, towards the head of the Sounds, rests against a vast complex of intrusive diorite and dioritic gneiss, and is intensely metamorphosed. It consists of granite-gneiss, various schists, and granular limestones that comprise what is called the Dusky Sound Series. To the westward the rocks show a gradually decreasing degree of alteration. For the most part they consist of mica-schist intercalated with numerous bands of chlorite-schist, and hornblende-schist. Altogether these schists comprise the division which has been referred to the Maniototo Series.

Near the coast the mica-schist series is overlain by slaty argillites, altered greywackes, and mica-schists in which mica is not strongly developed. These rocks have been ascribed to the Preservation Inlet Series of Lower Ordovician age. At Preservation Inlet, a few miles to the south of Dusky Sound, the blue slaty argillites of this series contain well-preserved graptolites.

The intrusive diorites extend from Preservation Inlet to the Darran Mountains, and thence to the Bryneira Range, far to the north of the Hollyford Valley. In the Sounds area they completely surround the Manapouri metamorphic series. Massives of granite, norite, gabbro, and dunite are associated with the dioritic complex, which has intruded rocks as late as the Maitaian of Permo-Carboniferous age. For wide stretches the diorites exhibit the effects of intense compressive stress, but as a rule they are otherwise not much altered. A fine section of these intrusive rocks is exposed in the Clinton and Arthur River cañons.

The Takitimu Mountains, which form the eastern wall of the Waiau rift-valley, are composed of argillites with red bands, and greywackes with which are intercalated beds of pale-green aphanitic sandstone and breccia. These rocks extend north to the Bryneira Range, on the east side of which they are intruded by diorite, gabbro, norite, and serpentine.

The floor of the Waiau Valley depression is covered with a thick sheet of faulted and tilted Middle Tertiary (Oamaruian) strata that contain valuable seams of brown coal. In many places these beds are richly fossiliferous. On the mountains to the east and west of the north arm of Lake Te Anau the tilted Oamaruian strata rise to a height of 5,000 ft. above the sea. In the floor of the Waiau Valley the Tertiary strata have been deeply eroded, and over large areas covered with Pleistocene glacial drifts.

TOPOGRAPHICAL FEATURES.

The dominant physical features of the area in review are the Waiau Valley depression, the north-south course of which was determined by powerful faults, the bare rocky Takitimu Mountains on the east side of the Waiau Valley, and the mountains of the main divide on the west, everywhere covered with dense forest.

The mountain region on the west of the Waiau Valley is an uplifted peneplain, ascending from 4,000 ft. in the south to 8,000 ft. in the north. On the western side this sloping plateau is gashed with deep, narrow, cañon-like Sounds and fiords that with their densely wooded slopes compose a picture of inspiring grandeur. On the eastern side lie Lake Manapouri and Lake Te Anau, the deep fiord-like arms of which reach far back into the main divide as if seeking to join hands with the fiords or fiord-valleys of the West Coast.

The Takitimu Mountains, ranging generally from 4,000 ft. to 5,300 ft. high, form the eastern wall of the Waiau Valley from the Mararoa Plain to the Ohai-Wairio depression, to the south of which the valley is bounded by the Longwood Range (2,000 ft. to 3,000 ft.). The Takitimu Mountains are arcuate in shape. They present their convex side to the Waiau Valley, with the result that the valley gradually narrows till the middle of the crescent, between Blackmount and Redcliff, is reached, beyond which the receding upper limb allows the valley at Manapouri to open out to its normal width. At the bottle-neck between the Takitimus and Titiroa Range the width of the valley varies from six to eight miles. To the north and south of this it widens out to twenty miles or more.

THE FIORDLAND PENEPLAIN.

The first reference to the plateau remnants of south-western New Zealand was made by Mr. E. C. Andrews (1906) in a paper* on the origin of the Sounds of south-west Southland. In a description of the characteristic topographical features he wrote: "Around Milford Sound, Lake Te Anau, and Lake Wakatipu there exist numerous sub-horizontal masses and long ridges, attaining heights of from 5,000 ft. to 6,000 ft. Above these rise peaks and masses to heights of 10,000 ft. Farther south sub-horizontal masses of much less elevation are encountered. These are apparently survivals of a flexed surface, the upland itself representing the advanced maturity of subaerial erosion (in pre-Tertiary times) when the land was at a much lower elevation."

If we inspect the recorded heights of the mountain-tops along the ranges of the main divide on the west side of the Waiau depression, and of the Livingstone and Takitimu mountains on the east side, we are led to the conclusion that these mountain-chains are, as suggested by Mr. Andrews, the remnants of an ancient peneplain that was at one time continuous from the Takitimus to the Tasman Sea on the west, long prior to the formation of the Waiau Valley. This view is confirmed by an examination of the country from the summit of the Bryneira Range on the north, or the Takitimu Mountains on the east, from which a commanding view of the whole landscape can be obtained. It is at once seen that the mountains of Fiordland, or Titiraurangi,† the Darran Mountains, the flat-topped Bryneira Range, the Takitimu, Livingstone, Eyre, and Humboldt mountains are the ruins of a continuous plateau that sloped gently to the south and south-east. At the time of its formation the Fiordland peneplain was merely the south-west continuation of the central Otago peneplain, of which the table-topped Hector, Carrick, Garvie, Old Man, Dunstan, Hawkdun, Rock and Pillar, Lammerlaw, and Tapanui ranges are striking survivals. The great valleys and lake-basins that separate these well-preserved block mountains owe their origin to powerful faults; while the smaller irregularities are the result of stream erosion along the course of minor dislocations.

Before the dissection of the Fiordland peneplain began the younger Palæozoic argillites and greywackes that compose the Takitimu and Livingstone mountains rested against the crystalline rocks of the Manapourian complex. The junction of the two systems followed approximately the course of the present Waiau depression.

An examination of the map shows that the principal arms of the western fiords and lakes lying west of the Waiau Valley follow two main directions, intersecting one another at right angles, one

* E. C. Andrews: The Ice-flood Hypothesis of the New Zealand Sound-basins, *Journal of Geology*, vol. 14, p. 28, 1906.

† The Maori name of the mountain-ranges lying west and north-west of Lake Te Anau. Titiraurangi = the land of many peaks piercing the clouds.

PLATE III.

Clinton Cañon from Top of McKinnon Pass.

[To face p. 14.

running about north-west and the other south-west. The result of this arrangement is that the Fiordland peneplain is dissected, notably on the seaward side, into what Sir James Hector in 1863 described as "cuboidal blocks." In 1909 Mr. R. Speight* also noticed these peculiar land-blocks, and states that their origin is difficult to explain in the light of our present knowledge. But he thinks "it is possible that the formation of the valleys was dependent in the first case on lines of crust-fracture, that the arms grew along these lines, and, in spite of valley-forms being modified, the main directions were always preserved."

The author's view is that the general orientation of the main valleys was determined by fractures that became worn by stream-action into valleys before the advent of the Pleistocene glaciation. During the glacial period the main valleys were deepened and modified by ice erosion. It was probably during the Late Pleistocene that the lateral "hanging-valleys" in the main fiords and mountain-valleys were formed. Sir James Hector† was the first to furnish evidence of the former great extension of the glaciers of Otago. Writing of the hanging-valleys of Milford Sound, he says, "The lateral valleys join the main one at various elevations, but are all sharply cut off by the precipitous wall of the Sound, the erosion of which was no doubt continued by a great central glacier long after the subordinate and tributary glaciers had ceased to exist" (*l.c.*, p. 460).

Mr. E. C. Andrews and Dr. P. Marshall have suggested that the formation of the Sounds and valleys intersecting the peneplain lying west of the Waiau depression was solely the work of ice erosion. On this question the author finds himself in substantial agreement with Mr. Speight's view that the general orientation of the Sounds and arms was determined by crust-fractures. The Fiordland peneplain is a faulted block, bounded on the west coast and along the Waiau depression by powerful faults, the geological and topographical effects of which are conspicuous. The proof of the existence of the minor crust-fractures postulated by Mr. Speight and the author can only be furnished by a detailed geological survey of the Sounds area.

The rounded and flowing contours of the mountains, the U-shaped valleys, cirques, truncated spurs, hanging-valleys, mountain tarns, and rock-basins are evidences of intense Pleistocene ice erosion. In the moulding and modifying of the land the ice has evidently removed an immense amount of material. In the Waiau, Manapouri, and Te Anau areas there are large accumulations of morainic material; but in the Sounds region, except at the entrance of Preservation Inlet and at Kisbee Bay (where there are large granite erratics), and in the lower end of the Cleddau and Arthur valleys (where there are small moraines), there is a conspicuous absence of ice-carried débris. This and the rounded contours of the headlands would suggest that the Pleistocene ice-sheet came down to the coast and discharged its rocky load on the floor of the sea. All the Sounds are shallower at the entrance than inside, and possibly this shoaling was caused by the accumulation of submarine moraines before the final retreat of the ice began.

Submergence of Peneplain and Formation of Coal-measures.

During the Early Miocene the Otago-Southland peneplain became submerged by a slow progressive transgression of the sea, and was covered with a relatively thin sheet of deltaic sediments. By the growth and decay of vegetation that established itself on the emergent banks these sediments were intercalated with seams of decomposing peaty matter that afterwards became transformed into coal. These basal sediments and their contained seams of brown coal constitute the well-known Miocene coal-measures of Otago and Southland.

The subsidence of the land continued into the Middle and Upper Miocene, and in consequence of the deposition and encroachment of the sea the deltaic coal-bearing beds became covered with a great succession of marine sediments.

The downward movement was arrested at the close of the Miocene, and early in the Pliocene there took place a rapid differential uplift. This upward, or positive, movement introduced

* R. Speight: Notes on the Geology of the West Coast Sounds, *Trans. N.Z. Inst.*, vol. 42, pp. 255–67, 1910.

† J. Hector: Geological Expedition to the West Coast of Otago, *Provincial Government Gazette*, Dunedin, 5th November, 1863.

powerful crustal stresses, which found relief by the formation of a network of dislocations that disrupted not only the older rocks in which the pre-Miocene peneplain had been carved, but also the covering sheet of deltaic and marine strata. The ancient peneplain became uplifted in places as cuboidal blocks bounded by parallel faults, and in other places tilted as sloping blocks where bounded by dislocations on one side only. The uplift was faster along the main divide than elsewhere, with the result that the general slope of the broken peneplain was towards the south-east and south.

Many of the uplifted blocks were separated by parallel faults, and, between some of these, slices of the Miocene coal-measures and associated marine strata were entangled, and thereby preserved from destruction. The Miocene strata lying on the surface of the uplifted peneplain were only partially consolidated, and disappeared rapidly before the activities of subaerial and ice erosion in the Pliocene and Pleistocene periods. Besides the many small infaulted masses of coal-measures that occur among the block mountains, the only evidences of the former existence of the Miocene rocks on the surface of the pre-Miocene peneplain are tabular beds and isolated blocks of sarsen stone, or a thin veneer of fine quartzose drift.

EXTENT OF POST-JURASSIC PENEPLAIN.

There is evidence that the Southland-Otago peneplain extended far beyond the limits of the provincial boundaries. The Kurow Range is the most northerly remnant in Otago. It is a well-preserved block mountain running north-west and south-east. On its northern side it is separated from Canterbury by the Waitaki depression, the floor of which is occupied by a faulted strip of Middle Tertiary (Oamaruian) strata.

The mountain-ranges of Canterbury have been recognized by Mr. R. Speight, M.Sc., F.G.S., as the residuals of an ancient peneplain that was, he thinks, probably a continuation of the Otago peneplain. The Canterbury ranges generally possess narrow uneven crests, on which there now remains no evidence to prove that the Canterbury peneplain was at one time covered with a sheet of Tertiary strata. But the faulted blocks of Upper Cretaceous and Tertiary strata, in the Trelissick Basin and other parts of Canterbury, may be accepted as evidence that such a covering sheet of marginal marine sediments did formerly exist in that region. His own view and the views of other geologists as to the existence of a post-Jurassic peneplain in the Canterbury area have been ably summarized by Mr. Speight* in a paper on "The Intermontane Basins of Canterbury," and need not be recapitulated here. Generally, his view is succinctly expressed in the concluding paragraph, in which he says, "Indeed, it seems reasonable to suppose that after the first formation as a folded range, at the close of the Jurassic or the beginning of the Cretaceous period, they [the Southern Alps] were reduced to a peneplain—this would take place towards the close of the Cretaceous period—and that on this peneplain the Tertiary beds were laid down; that subsequently they experienced vertical and perhaps differential uplift, with a certain amount of folding and undoubted faulting."

The author is in substantial agreement with Mr. Speight, but thinks that the littoral character of the sediments covering the peneplain would tend to show that the alpine chain was not completely suppressed by denudation, as he suggests. And, while agreeing that the peneplaining took place after the folding of the Trio-Jurassic rocks, the author is of the opinion that the existence of Upper Cretaceous strata resting on the folded Trio-Jurassic rocks, and underlying the Tertiary strata, is an evidence, as hereafter shown, that the peneplaining was completed not "towards the close of the Cretaceous period" but before the Cenomanian transgression of the sea began.

In their memoir on the "Geology of the Buller-Mokihinui Subdivision," Mr. P. G. Morgan, M.A., Director of the Geological Survey, and Mr. J. A. Bartrum, M.Sc., have shown that the peneplaining of the whole or greater part of the alpine area was completed in pre-Tertiary

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* R. Speight: *Trans. N.Z. Inst.*, vol. 47, pp. 336–53, 1915. In 1910 Mr. Speight described Mount Arrowsmith as a dissected peneplain (*Trans. N.Z. Inst.*, vol. 43, p. 319, 1911).

PLATE IV.

VIEW OF MOUNTAINS ON WEST SIDE OF LAKE TE ANAU, SHOWING EVEN CREST OF ANCIENT PENEPLAIN.

[To face p. 16.

times.* Farther north the Wainihinihi peneplain, apparently a continuation of the Mikonui peneplain, has been described by Dr. J. M. Bell, Ph.D., and Mr. Colin Fraser, M.Sc., as the result of Middle Tertiary peneplaining.†

Mr. Morgan recognized that the alpine folding took place during the Early Cretaceous. In the Upper Cretaceous there was a general subsidence, of which he says no historical remains are known to have survived on the west side of the main divide. This destruction of the Upper Cretaceous sediments was a consequence of the uplift and denudation that took place at the close of the Cretaceous or early in the Eocene.

The Eocene uplift described by Mr. Morgan (*Geol. Bull. No. 6 (N.S.)*, 1908, p. 37) appears to have been coeval with the uplift that witnessed the almost complete destruction of the Upper Cretaceous sediments covering the post-Jurassic peneplain in the Canterbury and Otago areas.

In their discussion of the probable age of the Wainihinihi peneplain, Dr. Bell and Mr. Colin Fraser suggest that perhaps this great physiographic feature may be the northern continuation of the ancient Fiordland peneplain mentioned by Mr. E. C. Andrews.‡

Mr. E. J. H. Webb, B.E.,§ believes that the Palæozoic Aorere Series was worn down by denudation practically to base-level, and that on this peneplained surface there was deposited an Early Tertiary succession of sediments that at one time covered the entire area of the Mount Radiant Subdivision.

In an admirable thesis " On the Genesis of the Surface Forms and Present Drainage-systems of West Nelson " Dr. Henderson|| recognizes the Whakamarama, Pikikiruna, Mount Arthur, Lyell, Murchison, Victoria, and Paparoa mountain-ranges as uplifted deeply dissected blocks, that are the remains of a great peneplain which extended from the Wainihinihi peneplain northwards to north Nelson. He concludes that the finely preserved block mountains of Otago first described by Professor Park are the remains of the Otago peneplain, which is merely the southern continuation of the alpine peneplain of Canterbury and Westland.¶

Writing in 1915 of " Former Peneplains in the Buller-Mokihinui Country," Mr. Morgan and Mr. Bartrum express the opinion that " the Westport highlands, and with them probably the greater part of central and western Nelson, furnish an excellent example of what has been termed a fossil peneplain."*

In their memoir on " The Geology of the Dun Mountain Subdivision, Nelson," Dr. J. M. Bell, Mr. E. de C. Clarke, and Dr. P. Marshall** propound the view that " the mountainous hinterland is thought to form part of that old faulted peneplain—representing a former approximation of the land to sea-level—which covers so much of the northern part of the South Island."

The axial chains of the North Island are, for the most part, composed of folded argillites and greywackes of Trio-Jurassic age. The axes of the main folds run north-east and south-west. A review of the existing physiographic features and distribution of the Tertiary marine strata appears to indicate that the present mountain-ridges represent uplifted remnants of an ancient peneplained surface that at one time extended from north Auckland to Wellington, and westward to Nelson.

In a discussion of the origin of the surface forms of the ridges surrounding Wellington Harbour, Dr. J. M. Bell†† expresses the opinion that the crests of all these ridges represent various levels of an old peneplained surface.

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* P. G. Morgan and J. A. Bartrum: *Geol. Bull. No. 17 (N.S.)*, p. 49, 1915.

† J. M. Bell and Colin Fraser: *Geol. Bull. No. 1 (N.S.)*, p. 26, 1906.

‡ E. C. Andrews: The Ice-flood Hypothesis of the New Zealand Sound-basins, *Journal of Geology*, vol. 14, No. 1, 1906.

§ E. J. Herbert Webb: The Geology of the Mount Radiant Subdivision, Westport Division, *Geol. Bull. No. 11 (N.S.)*, pp. 8 and 9, 1910.

|| J. Henderson: *Trans. N.Z. Inst.*, vol. 43, pp. 309–11, 1911. See also Bell, Webb, Clarke: *Geol. Bull. No. 3 (N.S.)*, p. 24, 1907.

¶ J. Henderson: *loc. cit.*, pp. 310–11. J. Park: *Geol. Bull. Nos. 2 and 5 (N.S.)*, 1906 and 1908. And J. Park: *Geology of New Zealand*, pp. 10, 11, 144, 1910.

** *Geol. Bull. No. 12 (N.S.)*, pp. 9 and 10, 1911.

†† J. M. Bell: The Physiography of Wellington Harbour, *Trans. N.Z. Inst.*, vol. 42, p. 535, 1910.

As far back as 1886 Professor Park* showed that newer Miocene strata rise from near sea-level to a height of 3,500 ft. on the western slopes of the Ruahine Range, and to the same height on the southern slopes of the Kaimanawa Range. His view then was that the Tertiary strata rested on a wave-cut platform ; but in conformity with the new conceptions as to the evolution of surface forms he now thinks that deposition may have taken place on a peneplained surface over which the sea slowly transgressed. But in this area, as doubtless also in the South Island, the advancing sea would truncate obstructing ridges and spread the material in the adjoining hollows, thereby forming the emergent coastal marshes on which the vegetation of the Early Miocene coals flourished before final submergence took place.

The even height of the crest of the ridges of the Trio-Jurassic divide in the East Cape area, as seen between Motu and Opotiki, and the faulted blocks of Middle Tertiary strata that occur on the flanks of the divide itself suggest the view that the Ruahine peneplain reached as far north as East Cape. According to our present knowledge the great post-Jurassic peneplain extended from one end of New Zealand to the other, and completely dominated the Early Cretaceous landscape ; afterwards it formed a prepared platform for the deposition of the later Cretaceous and Tertiary sediments. It possibly exercised a softening effect on the climate of these times. As a distinctive name and to facilitate reference it has been called Tahora.†

The character of the Cretaceous and Tertiary sediments proves that the great Tahoran peneplain was everywhere marginal to the highlands of the axial divide, the trend of which had already been determined by the Early Cretaceous diastrophic folding. And if we judge the past by existing geographical conditions we may not be far wrong in believing that the coasts of these ancient highlands were deeply embayed, and in places indented with sounds.

In Otago and Canterbury the main divide at the time of the Cenomanian transgression of the sea was probably a more or less continuous chain ; but in Nelson the Oamaruian limestone overlaps the coal-measures, and rests either on or close to the Palæozic basement rocks, which would tend to show that in this region there existed a chain of islands with relatively steep slopes.

The existence of Cretaceous and Tertiary strata at the Chatham Islands and at Campbell Island would suggest that the ancient Tahoran peneplain extended far to the east and south of New Zealand's present geographical limits.

AGE OF POST-JURASSIC PENEPLAIN.

Evidence will be adduced to show that the reduction of the peneplain to a base-level near sea-level took place after the folding of the Jurassic system and before the deposition of the Upper Cretaceous strata.

To discover the age of the ancient peneplain it will be necessary to make a critical examination of the rocks that are known to be concerned in its structure. In western Southland and Fiordland the peneplain was eroded in the dioritic complex of Late Palæozoic age, and in the gneisses and crystalline schists of the ancient Manapouri System ; in south-west Southland, in highly tilted Ordovician slates ; east of the present Waiau Valley, in argillites, greywackes, and aphanite breccias of Permo-Carboniferous age ; in central Southland, in folded Trio-Jurassic strata ; in western Otago, in the tilted and contorted mica-schists of the Palæozoic Maniototian System ; in central Otago, in Maniototian mica-schists that over a wide area are horizontal or inclined at very low angles, probably the result of recumbent folding ; in southern and eastern Otago, in the semi-metamorphic Kakanuian rocks that appear to follow the Maniototian conformably ; in northern Otago, in Kakanuian rocks and overlying argillites and greywackes of the Trio-Jurassic Hokonuian System. These latter extend into Canterbury, and compose the greater part of the Canterbury mountain-chains.

Similarly in Nelson we find folded Cambrian, Ordovician, Silurian, Permo-Carboniferous, and Trio-Jurassic rocks taking part in the structure of the ancient peneplain.

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* J. Park : On the Geology of the Western Part of Wellington Provincial District and Part of Taranaki, *Rep. of Geol. Explor. during* 1886–87, pp. 24–73, with map.

† *Tahora* = Maori for wide maritime plains.

In the North Island the only rocks known to be concerned in the formation of the ancient peneplain are the folded Trio-Jurassic argillites and greywackes that compose the main axial chains. No rocks younger than Jurassic take part in the structure of the land surface that became worn down into the great peneplain. Clearly, the base-levelling took place after the elevation and folding of the youngest Jurassic strata represented in New Zealand. The base-levelling was post-Jurassic, and, as will now be shown, must have taken place in the early half of the Cretaceous, before the world-wide Cenomanian transgression of the sea began.

Throughout New Zealand the Oamaruian Middle Tertiary strata occur as a marginal sheet flanking and surrounding the great axial chains. Almost everywhere these strata rest directly on folded and peneplained Jurassic or older rocks. But in some small areas strata that are known to be of Upper Cretaceous age are interposed between the peneplained older rocks and the Oamaruian, notably in the Trelissick Basin, Waipara and Weka Pass district, in the Clarence Valley, east coast of Wellington and Hawke's Bay, in Poverty Bay, and perhaps in north Auckland. From this it would appear that the peneplaining of the ancient Tahora took place during the early half of the Cretaceous and before the Cenomanian transgression of the sea began.

At the close of the Danian a general uplift took place, during which the weak Cretaceous beds were removed by denudation from the greater part of the peneplained Tahoran surface. Throughout the Miocene period there was progressive subsidence, during which Oamaruian sediments were laid down on the peneplained surface from which the Cretaceous strata had but recently been removed, and also on the remnants of the Cretaceous strata that had escaped destruction.

Where the Oamaruian System rests on Jurassic or older rocks its basement beds are conglomerates composed of material of local origin, but where it rests on Cretaceous strata basal conglomerates are absent. This doubtless arose from the circumstance that the rocks of the older systems were for the most part highly indurated, while the Cretaceous strata were soft or incoherent, and therefore incapable of providing resistant material for the formation of conglomerates. In consequence of these conditions the basal conglomerates are absent, or represented by clayey and sandy beds, wherever the Oamaruian rests on Cretaceous strata.

The events that led to the survival of patches of the Cretaceous strata offer scope for much interesting speculation. But there are two significant facts that, rightly interpreted, may assist us to a conclusion possibly not far from the truth. Wherever the Oamaruian rests on the Cretaceous strata, notwithstanding the sharply defined palæontological break, the physical unconformity between them is usually so small as to be almost indistinguishable. This is one outstanding fact; the other is that at the close of the Miocene the ancient peneplain and its covering pile of strata became broken up into blocks by many powerful faults.

The inference to be drawn from these conditions is that faulting began after the deposition and elevation of the Cretaceous strata, engulfing blocks of them in trough-like depressions in the ancient peneplain, where they were protected from destruction during the Eocene uplift. When subsidence began at the close of the Eocene the Oamaruian sediments were spread over both the surface of the uncovered peneplain and the down-faulted strips of Cretaceous strata. The deposition of the clayey and sandy Miocene sediments over the horizontal and little-worn Cretaceous strata has given a deceptive appearance of stratigraphical conformity that has perplexed many New Zealand geologists.

Throughout the Miocene there was a progressive downward crustal movement; and the character of the sediments shows that the rate of subsidence just kept pace with the rate of deposition. Apart from this subsidence, which may have been due to crustal sag arising from the shifting of material from the main axial chain to the floor of the adjacent seas, there was a cessation of all violent movement; but at the close of the Miocene there began a period of intense diastrophic disturbance which found expression in an uplift that was differential, being faster along the axial chain than elsewhere. In consequence of this unequal uplift, crustal adjustment was mainly effected by dislocation and warping. The major dislocations followed the planes of the Eocene faults, with the result that strips of Cretaceous and Miocene strata occur together in the montane basins. In some places the later faulting tilted and deformed these strata, as in the Trelissick Basin and in the Waipara district.

THE WAIAU FAULT.

The elongated form of the great lakes lying in the upper part of its basin led New Zealand geologists at an early date to speculate on the origin of the Waiau trough-like valley. Though unable to furnish evidence of crustal dislocation in this region, Hutton as far back as 1876 expressed the opinion that the Waiau Valley might possibly be a fault-trough (*Geology of Otago and Southland*). In his fault-map of New Zealand, published by the Geological Survey in 1892, McKay showed a great fault along the course of the Waiau Valley, to the north passing through Lake Te Anau. As McKay had never visited the Waiau or Te Anau country, we may assume that in placing the Waiau fault where he did he was in some measure influenced by Hutton's opinion. But there were other conceptions germinating in McKay's mind. At this time he was profoundly influenced by the views of Powell and other American geologists as to the topographical effects of faulting as exhibited in the Great Western Basin; and, following out this new conception, he concluded that all the dominant physical features of New Zealand were the result of crustal fracturing and displacement, a view generally endorsed by the author (1910) and by Dr. C. A. Cotton (1916).

The hypothetical views of Hutton and McKay as to the origin of the Waiau Valley are fully supported by the facts as recorded during the progress of the present survey.

The Waiau trough, including the basins of Lake Manapouri and Lake Te Anau, is bounded by two parallel faults, one to the east running along the foot of the Takitimu Mountains, the other to the west skirting the mountains of the main divide.

To the north of Lake Te Anau the faults converge and traverse the Clinton River diorites, but to the south of this lake the fault-trough lies between the Maitai Formation to the east and the intrusive series to the west.

The general trend of the Waiau trough is north and south. From the north end of Lake Te Anau to the sea the floor of the valley is occupied by a down-faulted strip of the Oamaruian Tertiary strata.

The effects of faulting are well seen near the head of Lake Te Anau (fig. 3), at Blackmount, at Monowai River, and between Blue Cliff and Port Craig. Almost everywhere along the lower flanks of the Takitimu Mountains the Tertiary coal-measures are down-faulted and generally much disturbed.

OTHER FAULTS.

The Waiau fault-system is intersected by many transverse faults. Between two of these lies the strip of coal-bearing strata that extends from the Waiau Valley to Nightcaps. This down-faulted strip occupies the depression separating Longwood Range from the Takitimu Mountains. The Ohai trough is itself intersected by the Wairaki step-faults that run nearly parallel with the great Waiau fault. The displacement of these ranges from 10 ft. to 50 ft., and has broken the Ohai coalfield into many small blocks.

Along the lower slope of Twinlaw the coal-measures are faulted and tilted towards the south. Generally the boundary of the Tertiary strata along the south side of the Wairio-Ohai coalfield coincides with the course of the Twinlaw fault.

To the north-east the Quested fault forms the north-east boundary of the Ohai-Nightcaps coalfield. This fault can be traced from the Ohai school to Quested's, and from there to the eastern boundary of the Nightcaps coal-measures.

To the east the Nightcaps coal-area is bounded by a fault that runs along the foot of the ridge known as Ritchie's. The coal dips towards the east, and is cut off on reaching the fault.

In the Waiau Valley the Middle Tertiary strata are tilted by transverse faults at Digger's Hill, and between Ligar Creek and Lake Monowai.

It may be surmised that the great fiord-like arms of Lake Manapouri and of Lake Te Anau follow the course of powerful faults; but it is difficult to obtain structural evidence in support of this view, as the country rocks everywhere to the west of the lakes are massive diorites. It is certain, however, that the arms and the cañons that extend beyond them followed definite zones of weakness. As the dioritic rocks are fairly homogenous and but little altered, it may be postulated that the process which brought about the initial weakness was faulting accompanied by rock-shattering.

It has been claimed by some writers that the arms and cañons were excavated by the Pleistocene glaciers. There is no evidence in support of this view; but even if true it is certain that the glaciers would select the paths where the rocks were shattered, and therefore offered the least resistance.

ROCK-RENTS.

On the flat and hummocky ice-worn summit of the Livingstone Mountains, between Lake Gunn, near the source of the Eglinton River, and the upper Greenstone Valley, in a distance of three miles, there are several remarkable rents running parallel with the general north-south trend of the range. These rents are open chasms traversing the grass-covered lands. They lie nearer the Greenstone than the Eglinton edge of the mountain-wall.

The largest rent is over 200 yards long and 50 ft. deep; and ranges from a few yards to 10 yards wide at the top.

The rocks composing the range are greywackes and pale-green fissile argillites, interbedded with lenses of limestone and intruded by numerous small dykes of diorite. The dip of the sedimentary rocks is towards the west.

The rents seem to be of comparatively recent formation. They were certainly formed since the retreat of the Pleistocene ice-sheet.

Their origin is obscure. Possibly they may be earthquake rents, following ancient fault-planes, or gashes formed by the sagging or creep of the precipitous mountain-walls towards the profound Greenstone cañon.

CHAPTER III.

GEOLOGICAL HISTORY.

MAJOR DIASTROPHIC MOVEMENTS AND MOUNTAIN-BUILDING PERIODS.

The views of Dr. von Hochstetter, Captain Hutton, Mr. McKay, and Professor E. Suess as to the periods and directions of folding and land-movements that have affected the South Island have been ably reviewed by Mr. P. G. Morgan,* Director of the Geological Survey, in his memoir on the "Geology of the Mikonui Subdivision, North Westland," and need not be recapitulated here at any great length.

Captain Hutton† postulated a Middle Devonian folding, parallel to the existing main mountain-axis but some distance to the west of it. This movement was, he believed, followed by a Permian (probably) elevation and rock-folding along the same axis. In the Jurassic a third folding took place, resulting in the formation of the Alps, which were never again to be wholly submerged. A little before the Tertiary era, folding, accompanied by elevation, once more took place, giving the last touch to the internal structure of the mountains. That is, Captain Hutton recognized three periods of major diastrophic N.E.–S.W. movement, and one minor movement, the last in the Tertiary era. He regarded the Alps as the eastern half of a huge geanticlinal, the western half of which had been removed by denudation.

Much new information as to the structure and age of the rock formations has been collected since Captain Hutton wrote in 1899, and his views now require to be modified to bring them into harmony with our present knowledge. He failed to recognize the diastrophic character of the N.W.–S.E. folding of the Trio-Jurassic and older formations of Southland and Otago.

Professor Suess,‡ relying mainly on the geological literature furnished him by Sir Julius von Haast, F.R.S., and Professor Park, recognized two major directions of strike and folding that encountered one another almost at right angles—namely, the N.E.–S.W. folding along the axial chains of both Islands, and a N.W.–S.E. folding in Otago and Southland. He noted that the Trio-Jurassic formations were involved in both systems of folding, and stated that "the knowledge we have acquired in other parts of the earth lead us to conclude that in this region two *independent unilateral* chains meet in syntaxis" (*l.c.*, p. 144). He also suggested that the isolated patches of older rocks that occur between the East Cape and north Auckland were the summit of a north-west sunken range.

Mr. McKay§ always maintained that the present Alps did not exist as a mountain-chain before the Miocene.

Mr. Morgan‖ recognized a N.–S. and possibly N.W.–S.E. folding in the Permian; a N.W.–S.E. Late Jurassic folding over the present alpine area and much of Canterbury and Otago; and a folding along the present alpine chain at the end of the Cretaceous or in the Early Eocene.

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* P. G. Morgan: *Geol. Bull. No. 6 (N.S.)*, pp. 35-37, 1908.

† F. W. Hutton: *Trans. N.Z. Inst.*, vol. 32, pp. 159-83, 1900.

‡ Edward Suess: *The Face of the Earth* (English translation), vol. 2, p. 144, 1906.

§ A. McKay: *Rep. Geol. Expl. during 1890–91*, vol. 21, 1892; and *Mines Rep.*, C.-3, p. 181, 1893.

‖ P. G. Morgan: The Geology of Mikonui Subdivision, *Geol. Bull. No. 6 (N.S.)*, p. 37, 1908; and *Geol. Bull. No. 17 (N.S.)*, p. 69, 1915.

In the structure of the principal chains Professor Park recognizes five major diastrophic movements :—

(1.) The Tuhuan,* a Devonian N.E.–S.W. folding, accompanied by granitic intrusions.
(2.) The Atawhenuan,† a Late Permian N.–S. folding, accompanied by dioritic intrusions.
(3.) The Hokonuian, an Early Cretaceous N.W.–S.E. folding.
(4.) The Rangitatan, an Early Cretaceous N.E.–S.W. alpine folding, parallel with the Tuhuan; accompanied by ultra-basic intrusions. Thrust probably from east.
(5.) The Ruahine (Pliocene) differential uplift that elevated New Zealand after the Oamaruian submergence.

The Hokonuian and Rangitatan took place in syntaxis. The Ruahine was not a folding movement, but a simple uplift along the general axis of the Islands.

The Tuhuan (or Devonian) N.E.–S.W. folding was accompanied by vast granitic intrusions. This movement affected the Silurian, Ordovician, and older rocks of Westland and Nelson, and laid the foundation on which the Rangitatan alpine folds were afterwards reared.

The Atawhenuan (or Permian) N. S. folding involved the Manapouri gneisses and schists in Fiordland and the Kakanuian (Wangapekan) and Maitai rocks north of the Hollyford (Park). It was accompanied by the intrusion of the Clinton River diorites, diorite-gneisses, gabbros, and norites of Fiordland, Longwood Range, Bluff, and Stewart Island.

The Hokonuian was an Early Cretaceous N.W. S.E. movement that involved the Lower Ordovician (or Upper Cambrian) slates and mica-schists of Preservation Inlet (McKay); the Trio-Jurassic rocks of the Hokonui Mountains, Southland (Hutton); the mica-schists of central and western Otago (Park); the Trio-Jurassic argillites and schists of north Otago (Park); the Pikikiruna and older Palæozoic rocks of north Nelson,‡ Mount Radiant,§ and Paparoa Range;|| the Permo-Carboniferous and Triassic rocks of Nelson (Park).

The Rangitatan was an Early Cretaceous N.E.–S.W. movement that folded the Trio-Jurassic rocks forming the axial chains in both Islands. It was evidently a revival of the Devonian folding, and was accompanied by extrusions of ultra-basic magmas.

The Ruahine (Pliocene) movement elevated the present chains after the Oamaruian (Miocene) submergence. It was differential, and accompanied by profound faulting, and by vulcanicity and seismic disturbance which have continued, with intervals of rest, up till the present day.

The N.E.–S.W. Rangitatan folding movements laid the framework and determined the structure and direction of the axial chains of both Islands.

The N.W.–S.E. Hokonuian movement folded and elevated the Hokonuis in Southland, and the chains of western Otago and Nelson. These chains meet the N.E.–S.W. folding in syntaxis, run transversely to the present axial chains, and end abruptly at the coast.

The Ruahine (Pliocene) uplift was not orogenic, but epeirogenic, and, being differential, was accompanied by profound faulting. In the trough-faults, rift-valleys, and montane basins formed during this movement strips of Cretaceous and Tertiary strata became deeply involved. In no case do rocks of post-Jurassic age take part in the mountain-making folds. The Pliocene uplift was accompanied by intense volcanic activity along the east coast of the South Island, and generally throughout the North Island. Mount Egmont, Ruapehu, Ngauruhoe, and other great volcanoes in the middle of the North Island date back to the Pliocene; and the vulcanicity which started them has continued, with periods of quietude, up till the present day. Seismic movements, of a wider range than those directly connected with volcanic outbursts, have accompanied the vulcanicity. They are traceable to the jolts arising from crustal adjustments along powerful faults that were formed, or rejuvenated, by the Pliocene uplift. Great faults are of slow growth.

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* Tuhuan was the name given by Dr. J. M. Bell and Mr. C. Fraser to the granite complex of north Westland.

† Atawhenua is the Maori name of the Sounds country of south-west Southland = Land of the shadows, or shadow-land.

‡ J. Park: On the Geology of Collingwood County, *Rep. Geol. Expl. during 1888–89*, No. 20, p. 228, 1890.

§ E. J. H. Webb: The Geology of Mount Radiant Subdivision, *Geol. Bull. No. 11 (N.S.)*, p. 9, 1910.

|| P. G. Morgan: The Geology of Greymouth Subdivision, *Geol. Bull. No. 13 (N.S.)*, p. 50, 1911.

The Rangitatan folding gave New Zealand two parallel systems of folded chains—the South Island main divide, which terminates abruptly to the north of Cook Strait, and the Kaikoura chains, which end at Cook Strait. The latter are represented in the North Island by the geologically similar Tararua and Ruahine ranges; but, except the Kaimanawa Range, there is no highland in the north in the line of the South Island main divide. In 1892, boulders of granite and gneiss were discovered by Professor Park* in a conglomerate at the base of the Middle Tertiary Oamaruian beds of the upper Waipa, east of Kawhia. Since that date gneissic plutonic rocks have been discovered in conglomerates in the gorge of the Waipaoa River, Poverty Bay (Sollas and McKay, 1906); in the Whangaroa district (Bell and Clarke, 1909); in the Hautotara Mountains of south-east Wellington (Sollas and McKay, 1906); at Albany, Lucas Creek, Waitemata Harbour (Bartrum, 1920); and Great Barrier Island (Bartrum, 1920).†

Granite and crystalline metamorphic rocks are not known in place in the whole of the North Island. Professor Suess believed that their presence as boulders in the Waipa beds supported the view which postulated that the South Island alpine chain at one time extended to the north, forming the backbone of the North Island. He suggested‡ that the northern prolongation of the Alps had sunk beneath the surface. This subsidence, he thought, may have caused the volcanic outbursts, which have since buried the highest summits of the sunken Alps.

The Kaimanawa Range lies in the prolongation of the main divide of the South Island. This range and the isolated outcrops of Trio-Jurassic rock at the sources of the Wanganui, Mokau, and Waipa rivers may be remnants of the sunken axial chain in the north.

The north-west peninsula of the North Island is a feature that departs abruptly from the N.E.–S.W. course of the axial Ruahine Range. It consists of a chain of isolated outcrops of Trio-Jurassic rocks, generally of low relief and covered with a broken sheet of Middle Tertiary strata. On the highly denuded surface of these strata there lies a pile of andesitic and rhyolitic lavas, tuffs, and breccias, the former traversed by gold-bearing veins.

The Mesozoic basement rocks strike towards the north, with deviations to the north-west, and more rarely to the north-east. The northerly strike corresponds with the direction of the Atawhenuan folding of the ancient Palæozoic rocks of Southland, western Otago, and north Nelson, and lies athwart the trend of the Rangitatan folding.

The northerly strike of the Trio-Jurassic rocks in the north-west peninsula may have arisen from a revival of the N.–S. Atawhenuan folding in syntaxis with the Early Cretaceous Rangitatan folding along the axial chain of the North Island. The N.W.–S.E. trend of the submerged chain forming the framework of the north-west peninsula was determined by block-faulting during the Ruahine (Pliocene) uplift, the faulting being accompanied by intense volcanic activity along the main fault-lines.

SOME GEOGRAPHICAL RELATIONSHIPS OF NEW ZEALAND.

When viewed as a part of the great world landscape New Zealand appears as a wrinkle on the surface of the lithosphere; but, though geographically isolated, it must bear a definite relationship to the adjacent parts of the earth's surface, whether these be ocean deeps or dry land. Though so isolated, New Zealand contains within its narrow borders representatives of most of the Palæozoic, Mesozoic, and Cainozoic formations. Moreover, its structure is that usually associated with areas of continental dimensions; and for that reason it is often spoken of as an island of the continental type. It is a miniature continent; and the occurrence in its framework of thinogenic§ rocks, ranging from the earliest geological epochs to the present day, is undeniable evidence that it stands on a subcrustal foundation of great stability.

Alternating elevation and submergence of its coasts have succeeded one another from the earliest ages. During periods of elevation its borders have been enlarged; during periods of

* J. Park: *Trans. N.Z. Inst.*, vol. 25, pp. 353–62, 1893.
† J. A. Bartrum: *Trans. N.Z. Inst.*, vol. 52, pp. 422–30, 1920.
‡ Edward Suess: *The Face of the Earth* (English translation), vol. 2, p. 146, 1906; and vol. 4, p. 318, 1909.
§ Greek, *this, thinos* = shore or shallow-water sediments.

submergence, diminished; but throughout all the vicissitudes of geological happening, including the making and foundering of continents elsewhere, the New Zealand area has maintained its identity as a resistant segment of the earth's crust.

This remarkable persistency lends powerful support to the doctrine that maintains the permanency of the great oceanic basins and continents. But the subject is beset with difficulties; and, though the general thesis is certainly true, its proof is well-nigh impossible. The suggestion of Harker and other writers that two types of continental tectonics can be traced—the Pacific and Atlantic, each dominated by a distinctive type of effusive magma, the calcic and alkalic—can no longer be entertained.

It has been established that in certain regions volcanic activity and seismic disturbance are restricted to certain linear or curvilinear lines, or zones, that follow the course of powerful crustal fractures. But crustal fracturing and faulting are merely an expression of geotectonic folding; hence in this chain of events we may have (1) folding, (2) fracturing and faulting, (3) vulcanicity and seismic disturbance.

Taking this thesis as a starting-point, Professor Suess,* in a masterly review of the wider relationships of the land areas of the South Pacific, attempts to define the course of the major crustal folds in which New Zealand has been involved in later Tertiary times. He prefaces his view by a restatement of Dana's observations that the elongated oceanic depressions, or deeps, lie in front of the more recent folded ranges. He agrees with Supan that these depressions, or fore-troughs, are connected with folding, and supports the hypothesis that "these depressions mark the subsidence of the fore-land beneath the recent folds" (*l.c.*, p. 295). Farther on he says, "With one or two exceptions, all marine abysses which sink below a depth of 7,000 metres [about 4,000 fathoms] are fore-deeps in a tectonic sense, and indicate the subsidence of the fore-land beneath the folded mountains."

To be consistent with Dana's hypothesis of mountain-building the word "beneath" should be replaced by the words "in front of." It is difficult to understand how the fore-land could sink beneath the recent folds, except by overloading and seaward creep of the mountain-folds as postulated by Dana. It appears more probable that the oceanic deeps are sunken parts of the crust, and that the mountain-chains represent the parts where the compressive stresses set up by the sinking of the troughs found relief by folding and fracturing, accompanied by magmatic effusions.

In his review of the South Pacific, Professor Suess (*l.c.*, p. 311 *et seq.*) recognizes three main zones, or arcs, of folding, fracturing, and vulcanicity. The first Australian arc extends from New Ireland to Hunter Island. This long chain includes as its principal members New Ireland, the Solomon and Santa Cruz islands, and the New Hebrides, all of which possess many characters in common. This line is characterized by one direction of strike, forming an arc slightly convex to the north-east. The second Australian arc includes the Fiji Islands, which lie between the volcanic lines of the New Hebrides and Tonga. The third Australian arc includes as its principal members the Tonga and Kermadec Islands and the Ruahine Range of New Zealand.†

OUTLINE OF GEOLOGICAL HISTORY.

As a consequence of the large amount of palæontological work and field research carried out during the past quarter of a century, the major events in the geological history of New Zealand in the Cainozoic epoch are now well known. But our knowledge of the Palæozoic and Mesozoic epochs is still fragmentary and meagre. Whole chapters are missing; and the few broken pages that have been found are blurred and difficult to piece together in a connected story.

* E. Suess: *The Face of the Earth* (English translation), vol. 4, pp. 295–318, 1909.
† E. Suess: *l.c.*, vol. 2, p. 146, 1906; and vol. 4, p. 318 *et seq.*

The Story of the Rocks.

From a study of its rock-structure we know that New Zealand is merely an elongated residual of a greater land now submerged below the sea. It is a crustal block standing on a platform of ancient crystalline rocks, and bounded to the east and west by powerful faults. We have evidence of rock-folding and mountain-building in many different epochs, of fracturing and igneous intrusion, of the deposition of sediments along many ancient strands of which there is now no trace, of terrestrial and marine forms of life that flourished for a time and disappeared, and of other forms related, at first distantly and later more nearly, to the life of the present day.

When we examine the organic remains embedded in the strata forming the framework of the country we discover that the sea, at more than one epoch, spread over the areas now occupied by the present mountain-chains.

The oldest rocks in New Zealand are certain gneisses, schists, and limestones that extend from south-west Southland to Nelson, along the west side of the main axial chain. They comprise in part the Manapouri System of Captain Hutton in western Southland, the Arahura Series of Dr. Bell, Mr. Fraser, and Mr. Morgan in Westland, the Pikikiruna Series of Professor Park in north Nelson, and the mica-schists of central and eastern Otago. These rocks are highly metamorphosed, and all traces of organic remains have been completely obliterated.

The chlorite-schists and hornblende-schists are evidently altered igneous rocks, but the associated slates, mica-schists, phyllites, and limestones are of sedimentary origin. The origin of the gneisses is not so clear; these rocks occur in places as massive bands of great width, and in other places are intercalated with thin bands of mica-schist and limestone; they may be in part igneous and in part clastic.

The phyllites and mica-schists were originally composed of argillaceous and sandy material derived from the denudation of an ancient land composed mainly of granite and gneiss. Of this land nothing is known except that it extended to the north-east. There is nothing to tell us whether it lay towards the Antarctic or the Pacific.

In Fiordland the crystalline metamorphic rocks dip towards the west, and in Westland towards the east. The structure is that of a great anticlinal, the axis of which runs in the south towards the north, and in Westland towards the north-east.

After an interval of unknown duration certain argillaceous and arenaceous sediments were laid down on the floor of the sea laving the shores of the pre-Ordovician land. In process of time these sediments became indurated and altered into argillites, slates, quartzites, and mica-schist.

The slaty rocks are usually graphitic, and contain the oldest recognizable organic remains known in New Zealand. At Preservation Inlet, and at the Slaty River in north Nelson, they contain graptolites that have been identified as belonging to the Ordovician epoch. In the north the Ordovician rocks are followed by fossiliferous Silurian strata that were apparently laid down along the shore of the pre-Ordovician continent.

Though considerably modified by subaerial denudation and rock-folding, there is good ground for the belief that the Archæan continent which provided the detritus for the formation of the Dusky Sound crystalline schists also furnished the sediments for the later Ordovician, Silurian, Permo-Carboniferous, and Trio-Jurassic formations.

So far as known, rocks of Devonian and Early Carboniferous age are unrepresented in New Zealand. From this we gather that during this great hiatus the New Zealand area was dry land, probably forming an extension of the Archæan continent which furnished the sediments of the Silurian and older formations.

Late in the Carboniferous there began a downward movement, with a consequent transgression of the sea, on the floor of which clayey, sandy, and calcareous deposits were laid down. These deposits constitute what is now called the Maitai Formation of Permo-Carboniferous age, and they were laid down marginal to the ancient continent.

After the deposition of the Maitai Formation there was a period of intense folding, accompanied by the intrusion of dioritic and granitic magmas along a line varying from N.–S. to N.E.–S.W. The date of these intrusions was certainly pre-Triassic, and later than Permo-Carboniferous.

The Trio-Jurassic is represented by a tremendous pile of deltaic and marine strata, which are intercalated with beds of coarse granitic conglomerate in both Islands. The scarcity of organic remains in this great formation would tend to suggest that the sediments of which it is composed were transported to the sea by large rivers draining a land of continental dimensions. This ancient Mesozoic continent may have been a remnant of the Palæozoic Gondwanaland of the South Pacific. If this view be sustained we may reasonably conclude that the lands which provided the sediments of the Palæozoic formations of New Zealand lay towards the north, and not towards the Antarctic.

In the Early Cretaceous the New Zealand area was crumpled by two crustal movements, which ridged up the Jurassic and older strata in two systems of mountain-building folds—one a N.E.–S.W. folding parallel with the axis of the main chain, the other a N.W.–S.E. folding. The N.E.–S.W. definitely determined the direction of the axial chains, and appears to have been a revival of the Late Palæozoic diastrophic movement. It dominated the N.W.–S.E. folding, and was accompanied by the extrusion of ultra-basic magmas in north-west Otago, Nelson, and north Auckland.

The Early Cretaceous was a period of great fluviatile activity; and at the close of the Albian the newly folded chains were already worn down to narrow ridges, or a chain of islands, bordered with peneplained lands approaching the sea base-level. At this time the Inland Kaikoura and Ruahine mountains formed an unbroken folded chain running parallel with the continuation of the South Island alpine chain to the north, which had not sunk below Cook Strait, and the volcanic region of north-west Wellington. What is now the Seaward Kaikoura Range occurred as a secondary fold to the south-east of the Inland Kaikouras.

With the emergence of these chains in the Early Cretaceous the excavation of the Clarence Valley began, the rate of erosion being accelerated by the anticlinal arrangement of the Trio-Jurassic strata and the shattering effects of the Clarence fault.

During the Albian stage, at the time the peneplaining of the axial chains of the mainland was in progress, the sea began to invade eastern Marlborough, where it laid down sediments that have been shown by Mr. H. Woods, F.R.S.,* on the evidence of their fossil contents, to be Lower Utatúr (Albian). At the same time Albian sediments were deposited on the coasts of east Wellington, Hawke's Bay, and Poverty Bay, along the east side of the Ruahine chain.

At the close of the Albian the Cenomanian transgression became general; and soon after the sea encroached on the newly formed coastal peneplain, Tahora, that everywhere fringed the main chains, which were themselves reduced to features of low relief. On the surface of the peneplain, and also on the Albian beds already deposited, sediments were laid down by the advancing sea throughout the remainder of the Upper Cretaceous.

At the close of the Danian stage the world-wide recession of the sea began; and, though not a great retreat, it permitted the removal of the weak post-Albian beds from the greater part of the uplifted Tahoran peneplain, and in part from the Clarence depression. The absence of identifiable Eocene beds would tend to show that the uplift was of longer duration in New Zealand than in western Europe.

Late in the Eocene there began a general subsidence, which continued in the Wanganui–Hawke's Bay region till the close of the Pliocene. During the Miocene the Oamaruian Formation was deposited, in some areas on the slightly eroded surface of the surviving Upper Cretaceous strata, but mainly on the surface of the newly uncovered Trio-Jurassic and older rocks of the Tahoran peneplain.

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* H. Woods: The Cretaceous Faunas of the North-eastern Part of the South Island of New Zealand, *Pal. Bull. No. 4*, N.Z. Geol. Surv., p. 4, 1917.

To the north and south, owing to crustal warping, deposition ceased at the close of the Miocene. Before the close of the Miocene there began a differential uplift in Auckland and Otago, pivoting on the Napier–Wanganui zone, where the movement still continued downward, this arising from the thrust accompanying the tilting of the ends of the main chains.

Middle Tertiary rocks are well represented in south-west Southland; but, in consequence of the uplift that began at the close of the Miocene, marine Pliocene strata are everywhere absent in the south. The Pliocene uplift took place along the course of the axial chains. It was a revival of movement along the north-east and south-west direction of folding, but was not accompanied by rock-folding, and was orogenic only in the sense that it uplifted the present chains and gave them the finishing touches. The upward movement was more rapid along the axes of the chains than along the coasts. And as a consequence of the tensional stresses caused by this differential uplift the Miocene and Older Pliocene strata were not upraised equally. In some areas they rise upward from the coast by a gentle ascent; but where they attain their greatest elevation they ascend by a series of step-faults.

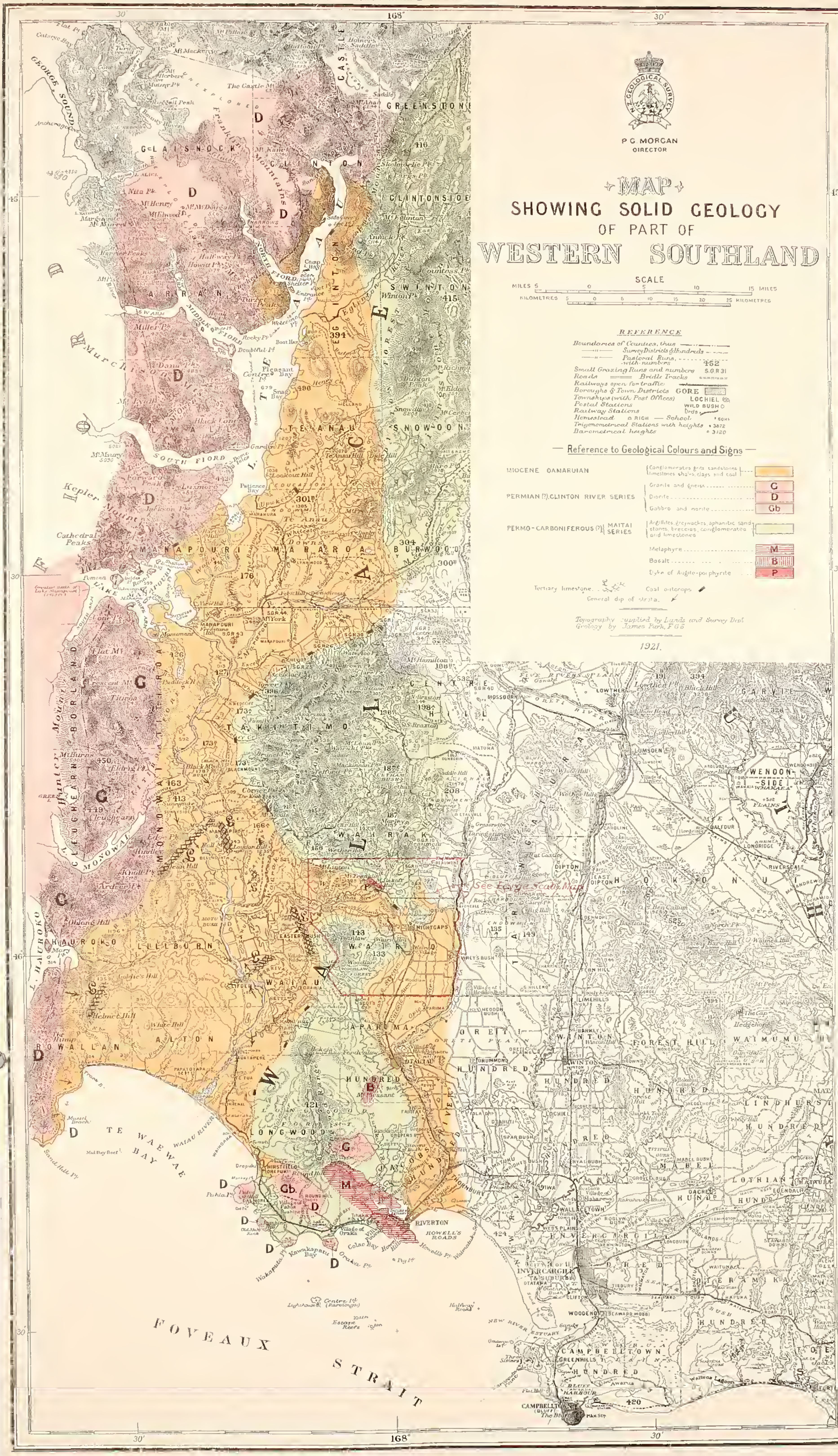
Generally, throughout both Islands the stresses introduced by the differential uplift were relieved by the formation of powerful faults, some of which followed the course of ancient dislocations. During the progress of the Pliocene movement many blocks and strips of the Upper Cretaceous and Middle Tertiary covering sheet of strata became entangled in trough-faults, where they were protected from the destruction that removed the similar covering strata from the uplifted mountain-blocks. In this work of destruction the Pleistocene ice-sheet played a prominent part, especially in the highlands of Southland, Otago, and Canterbury.

It was during the progress of the Pliocene uplift that the Miocene strata were faulted along the floor of the Waiau rift-valley, and uptilted high on the flanks of the ranges to the east and west of Lake Te Anau. The Pliocene uplift was accompanied by a lowering of temperature, and with the advent of the Pleistocene there began a period of intense refrigeration. At first there was an increase of fluviatile activity, and piles of gravel-drift were spread over the valley-floors to a great depth. At the time of maximum cold the land lay in the grip of an ice-sheet that filled the lake-basins and descended the Waiau Valley. The ice scored and grooved the sides of the mountain cañons, regraded the valley-floors, truncated projecting spurs, and carried a load of rocky débris to the lowlands. With the coming of a warmer cycle the ice began its homeward retreat to the higher mountains, where remnants still survive. The retreat was accompanied by a revival of fluviatile activity. The Waiau River, which during the early part of the Pleistocene had piled up a flood-plain to a level reaching many hundred feet above the present bed, began its work of destruction, and, aided by a general uplift of the land or recession of the sea, has now removed its ancient drifts, leaving only broad terraces that contour around the sides of the valley and mark the height of the Pleistocene flood-plain.

The Succession of Life.

The bands of limestone associated with the schists and gneisses of the Cambrian Dusky Sound Series would lead us to the belief that some form of marine life existed in these seas in pre-Ordovician times. Elsewhere the Cambrian seas teemed with a varied and well-developed life, but no trace of fossiliferous rocks of this period have been found in New Zealand. If fossils ever existed they have been obliterated by the intense metamorphism the pre-Ordovician rocks have suffered.

The Ordovician graptolites of Preservation Inlet and north Nelson are the oldest form of life known in New Zealand. The genera that have been identified are closely related to forms well known in the Ordovician of Australia and Europe. Graptolites are now regarded as an ancient and aberrant type of the Hydrozoa. In many respects they are related to the Sertularians of the present day; but, unlike these, they were free. Their world-wide distribution and the restricted vertical range of certain types appear to indicate the means of rapid dispersal that a continuous sea from north to south would afford. At even this early period in the earth's history



N.Z. GEOLOGICAL SURVEY
P. G. MORGAN
DIRECTOR
MAP
SHOWING SOLID GEOLOGY
OF PART OF
WESTERN SOUTHLAND
SCALE
MILES 5 0 5 10 15 MILES
KILOMETRES 5 0 5 10 15 20 25 KILOMETRES
REFERENCE
Boundaries of Counties, thus
Survey Districts & Hundreds
Pastoral Runs, with numbers 452
Small Grazing Runs and numbers S.G.R 31
Roads
Bridle Tracks
Railways open for traffic
Boroughs & Town Districts GORE
Townships (with Post Offices) LOCHIEL
Postal Stations WILD BUSH
Railway Stations
Homestead RICH
School
Trigonometrical Stations with heights 3872
Barometrical heights 3120
Reference to Geological Colours and Signs
MIOCENE OAMARUIAN
Conglomerates grits sandstones limestones shales, clays and coal
PERMIAN (?) CLINTON RIVER SERIES
Granite and gneiss G
Diorite D
Gabbro and norite Gb
PERMO-CARBONIFEROUS (?) MAITAI SERIES
Argillites, greywackes, aphanitic sandstones, breccias, conglomerates and limestones
Melaphyre M
Basalt B
Dyke of Augite-porphyrite P
Tertiary limestone
Coal outcrops
General dip of strata
Topography supplied by Lands and Survey Dept.
Geology by James Park, F.G.S.
1921.
GEORGE SOUND
CASTLE
GREENSTONE
CLINTON
CLINTONSIDE
GLAISNOCK
ARRAN
SWINTON
TE ANAU
SNOWDON
MANAPOURI
MARAROA
BURWOOD
TAKITIMO
CENTRE
WAIAU
LILLBURN
ALTON
HAURОКО
ROWALLAN
APARIMA
LONGWOOD
HUNDRED
RIVERTON
TE WAEWAE BAY
FOVEAUX STRAIT
INVERCARGILL
CAMPBELLTOWN
WINTON
FOREST HILL
WAIMUMU
WENDON SIDE
LUMSDEN
DIPTON
See Large Scale Map
168°
30'
45°
46°

the framework of the great continents had already assumed definite form. And the conception of a connected sea, with uniform conditions of deposition and climate, over the vast area covered by the deposits containing identical graptolites, with its postulate of contemporaneity of life in all parts, is in conflict with the distribution of recent organisms. The identical species cannot have been produced simultaneously in all the areas where their remains are now found. They must have been dispersed by migration from one or other of these areas, or from some centre of origin still unknown; and this dispersal must have been spread over a long period of time. Deposits may be spoken of as "homotaxial" when they contain identical or closely related fossils, but this does not imply that they have been laid down at precisely the same time everywhere.

Silurian rocks have not been recognized in Southland or Otago, but are well represented in the Reefton and Baton districts in Nelson. There they contain a rich marine fauna that includes Trilobites (an ancient form of crustacean), many molluscs, brachiopods, and corals. Generally the life of this period indicates shore conditions of deposition and the prevalence of warm seas. The genera show a closer relationship to the Silurian life of western Europe and North America than to that of Australia. This tends to show that considerable geographical changes took place at the close of the Ordovician. The continuous sea still extended to the north; but a land ridge separated New Zealand and Australia, and in the seas to the north-west of this ridge the Australian Silurian types developed along lines that differentiate them from the New Zealand – Atlantic contemporary forms.

At the close of the Silurian there began a regional uplift which continued throughout the Devonian and well into the Carboniferous. As a consequence of this elevation no marine deposits were laid down in the New Zealand area till the close of the Carboniferous, when a general transgression of the sea began. This transgression continued up till the Permian, and it was at this time that the Permo-Carboniferous Maitai beds were laid down. The material composing these beds ranges from fine muds to coarse conglomerates and breccias. Associated with these beds there are beds of limestone; some of these are thin short lenses, but others are deposits of great thickness. In the Bryneira Range, north of the Hollyford Valley, the Maitai limestone bands and alternating aphanitic sandstones are over 2,000 ft. in thickness.* Clearly a land area with mountain-chains drained by streams, and a spacious sea swarming with calcareous organisms, existed in the New Zealand region of the Permo-Carboniferous. It was earlier suggested that the detrital material of the Ordovician and Silurian rocks was derived from a land-mass lying to the west or north-west; and we are further tempted to suggest that the Permo-Carboniferous land was a remnant of the pre-Ordovician land. Glacial deposits of Late Palæozoic age have been recognized in Australia, India, South Africa, and Russia; and recently the author† has reported the discovery of striated boulders in a Maitai or Te Anau breccia at Taieri Mouth. It is evident that the Permo-Carboniferous lands throughout the greater part of the globe were high enough to support glaciers that descended to the sea. The alternative view is that the glaciation was not alpine, but arose from a secular refrigeration that affected the whole or greater part of the earth. This view is disproved by the abundant terrestrial flora and marine fauna of that period.

Though marine rocks of Permo-Carboniferous age occur in New Zealand, there is no trace of beds containing relics of the terrestrial flora of that period. Moreover, no trace is known of any Palæozoic land floras in these Islands, which is singular when we consider the great thickness of alternating argillites and sandstones that occur in the Silurian Baton River Series in association with rocks containing a shallow-water marine fauna. So far as the present evidence stands, the history of New Zealand as a land area begins with the Middle Trias. As a consequence, the relationship of New Zealand to the Permo-Carboniferous Gondwanaland that is believed to have occupied a large part of the Southern Hemisphere is still obscure. The fern-like *Glossopteris*,‡

* J. Park: *Rep. Geol. Expl. during 1886–87*, p. 132, 1887.

† J. Park: On the Occurrence of Striated Boulders in a Palæozoic Breccia near Taieri Mouth, Otago, N.Z., *Trans. N.Z. Inst.*, vol. 52, pp. 107–8, 1920.

‡ Greek, *glossa* = tongue, and *pteris* = a fern

which flourished all over that ancient continent, appears to be absent in New Zealand ; but many other land-plants that are commonly associated with that genus in the older Mesozoic of Australia, India, South America, and South Africa are present in the Mesozoic beds of the South Island. For the present the relationship of New Zealand to Gondwanaland must remain an open question.

The interval between the Permian and Middle Trias is unrepresented by recognizable sediments, but from the Middle Trias to the close of the Jurassic there was continuous deposition over the greater part of both Islands. The sediments of this period consist mainly of shales, argillites, sandstones, and conglomerates of deltaic and marine origin. Marine beds with a littoral fauna alternate with beds containing a terrestrial flora, but there is a remarkable absence of limestones or of beds that would indicate deep-sea conditions of deposition. The thickness of this great formation is over 10,000 ft., and from the bottom to the top the sediments indicate the proximity of a land subject to fluviatile denudation. The Middle Mesozoic was a period of progressive subsidence, and the rate of submergence kept pace with the rate of deposition. The accumulation of these sediments caused tremendous crustal stresses, accompanied by sagging in a narrow zone running parallel with the ancient shore-line. These stresses were cumulative, and at the close of the Jurassic started the Rangitatan rock-folding that originated the N.E.–S.W. axial chains. The origin of the contemporary N.W.–S.E. folding is unknown. The dominant Rangitatan movement was accompanied by faulting and intense local vulcanicity. The elevation of the New Zealand chains in the Early Cretaceous witnessed the submergence of the ancient Mesozoic land, from which the sediments that compose the folded rocks of the axial chains were derived.

The marginal distribution of the Middle Tertiary strata to the east and west of the present Alps tends to show that this submergence took place early in the Cretaceous. And the occurrence of Upper Cretaceous marine strata to the east, and their absence to the west—if that absence is not to be accounted for by denudation—may indicate that the sunken land lay to the west of the present Alps, as postulated by Hochstetter.

The fossils enclosed in the Trio-Jurassic rocks tell us that the land at that time was clothed with a mesophytic vegetation consisting of ferns, cycads, and conifers, while the contemporary seas swarmed with molluscs, brachiopods, and other marine life. The large size of the tree-trunks in the petrified Jurassic forest at Curio Bay, Waikawa, and the myriad mussels (*Mytilus*) enclosed in the marine beds of the Upper Trias prove that the climatic conditions were those we should now associate with the Temperate Zone.

The relationship of Mesozoic New Zealand to the other continents is still in doubt, this arising from the meagre knowledge we possess as to the processes of dispersal of plant and animal life. Many of the terrestrial plants are identical with, or closely related to, forms found in Australia, India, Siberia, Scotland, and England. This wide distribution of allied species appears to support the view that a more or less continuous land bridge stretched from New Zealand to north-west Eurasia in Mesozoic times. Moreover, the specific identity of some of the characteristic molluscan species of the New Zealand Trias, as of *Daonella* and *Monotis*, with those of the alpine Trias of Eurasia adds support to this view. It is well known that the free larvæ of molluscs are capable of rapid dispersal in a continuous sea ; and a continuous land bridge postulates a continuous shore. But while the northern lands were clothed with forests, in which the gigantic club-mosses *Lepidodendron* and *Sigillaria* and giant horse-tails (*Calamites*) were conspicuous, the lands of the Southern Hemisphere were occupied by an assemblage of plant-life dominated by what has been described as the "*Glossopteris* flora." It is possible that climatic conditions may have been responsible for the absence of this flora in Mesozoic New Zealand and western Europe.

The Jurassic period came to an end with a world-wide diastrophic movement accompanied by elevation. New Zealand, Tasmania, Australia, and the great continents were in great part converted into dry land, which lasted in North America, Eurasia, and Australia till the beginning of the Cretaceous, and in New Zealand till the Middle Cretaceous (Albian), except perhaps in the west of Auckland, where there are deltaic beds that have been ascribed to the Neocomian.*

The molluscan and reptilian Cretaceous faunas of north-east Australia and New Zealand are closely related; and this relationship may be taken as an evidence of a land connection joining these areas at that period.

The great crustal movements and the accompanying epochal changes in the world's fauna and flora that took place in the Northern Hemisphere at the close of the Cretaceous reached as far as New Zealand and Australia. The huge reptiles that haunted the Cretaceous deltas disappeared, and in the north mammals took their place on land. The flying reptiles were succeeded by birds, and forests of deciduous trees harboured swarms of insect-life.

It is probable that the land bridge between New Zealand and north-east Australia continued till the Eocene, and this may explain the absence of marine sediments of that period in Australia and New Zealand. The Eocene uplift came to an end towards the close of that period; and it was about this time that torrential streams piled up a vast thickness of fluviatile drift and angular rocky débris on the steeply sloping floor of the sea bordering the axial chains of New Zealand, and in this way built up the coastal platform on which the coal vegetation of the Early Tertiary flourished.

Towards the close of the Eocene there began a transgression of the sea that submerged the coastal lands in both hemispheres. In New Zealand the Eocene deltaic plains, with their accumulation of decaying vegetable matter, became buried beneath a thick sheet of marine sediments that constitute what is called the Oamaruian Formation.

The sheet of Upper Cretaceous sediments, that were laid down on the surface of the ancient New Zealand peneplain (Tahora) as a result of the Cenomanian transgression, were removed by denudation during the Eocene uplift, except in a few areas where they were protected in down-faulted depressions. As a consequence of this the Miocene Oamaruian rests partly on these Cretaceous remnants, but mainly on the uncovered surface of the peneplain.

Geologically and economically the Oamaruian is the most important of the Cainozoic formations in New Zealand. It consists of a succession of sediments ranging from the Oligocene or latest Eocene to the beginning of the Pliocene. The lowermost beds consist of terrestrial and deltaic sediments that are followed by marine clays, sands, and limestones.

The terrestrial and deltaic beds enclose valuable seams of lignite, brown coal, and bituminous coal, and comprise what is known as the Oamaruian coal-measures, which contain 85 per cent. of the available coal in the Dominion.

The character of the abundant molluscan fauna contained in the marine sediments tells us that the climatic conditions prevailing during the Middle Tertiary were semi-tropical—perhaps not unlike those of north Auckland of the present day.

At the close of the Miocene the Oamaruian covered the greater part of New Zealand. The author was the first to recognize that these isolated patches are the remnants of what was formerly a continuous marginal sheet that contoured around the partially submerged chains of the Older Tertiary period. This generalization suggested a new line of investigation, and soon led to a better understanding of the geographical conditions of these and later times.

Middle Tertiary strata occur at Campbell Island and the Chatham Islands. The inference to be drawn from this is that, though separated from Australia, these outlying islands still formed a part of the New Zealand mainland.

At the close of the Miocene the downward movement ceased, and there began, as already described on a preceding page, what has been called the Ruahine uplift, which followed the axial chains. The uplift was differential, and this introduced tensional stresses that were relieved by the fracturing of the Tertiary strata and uplifted rock-platform on which they rested. The fractures for the most part ran parallel with the axis of elevation. Faulting and the

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* E. A. Newell Arber; The Earlier Mesozoic Floras of New Zealand, *Pal. Bull. No. 6*, N.Z. Geol. Surv., 1917.

tilting of crustal blocks accompanied the uplift of the axial chains. It was at this time that the isolated blocks of Oamaruian strata scattered along the flanks of the ranges became engulfed in fault-fractures or left as broken tilted masses in troughs and intermontane basins.

During the progress of the Pliocene uplift the rains of that period removed the weak Miocene strata from the greater part of the uplands; and later the work of destruction was carried on by the Pleistocene glaciers. It was only along the coasts, and where sheltered in basins bounded by faults, that remnants of the once great sheet of Middle Tertiary sediments were able to survive.

The Pliocene uplift increased the area of New Zealand considerably, especially towards the north-west; but there is no evidence that any land connection was established at this period with Australia, South Africa, South America, or Antarctica.

The fauna of New Zealand contains a large Malayan element, and shows some relationship to the South American and Antarctic faunas. With the exception of a bat, which may have been wind-carried, there is an entire absence of endemic land-mammals; and generally the fauna, though showing a great variety of forms, is of a low type. Some orders are common to New Zealand and Australia, others to New Zealand and South America; while some orders common to Australia and South America are unrepresented in New Zealand. It is evident that the isolation of New Zealand must date back to the Early Tertiary.

Professor Gill has suggested that an Antarctic land was the common centre of dispersal. From this southern continent land bridges extended northward to South Africa, South America, and Malaysia, this last by way of New Zealand. These land bridges became disconnected with the parent land at different periods. The first break took place in the connection with South Africa, soon followed by a break with South America. The break between New Zealand and Malaysia took place before the spread of the marsupials began. It was probably after this that New Zealand became isolated from the southern continent.

CLASSIFICATION OF ROCK FORMATIONS.

The classification adopted for the purpose of this report is shown in the following table of rock formations:—

System.	Series.	Age.
Recent	River-gravels, beach-sands, &c.	Recent.
Pleistocene	(a.) High-level gravels, glacial drifts, and moraines (b.) Mararoa clays, and silts with lignite (c.) Orepuki clays, and silts with lignite	Pleistocene.
Wanganuian	Absent	Pliocene.
Oamaruian	(5.) Marine clays and sandy beds (4.) Limestone (3.) Sandstones and clays (2.) Fireclays, with seams of brown coal (1.) Conglomerates, grits, sandstones, and limestone	Miocene.
Unconformity	Period of uplift with faulting, but no folding	Eocene.
Waiparan	Absent in Southland	Upper Cretaceous.
Unconformity	Rangitatan N.E.–S.W. folding Hokonuian N.W.–S.E. folding	Lower Cretaceous.
Hokonuian	Shales, argillites, greywackes, and conglomerates	Juro-Triassic.
Unconformity	Atawhenuan folding, with intrusion of Clinton River diorites, &c.	Permian or Early Triassic.
Maitaian	Argillites, greywackes, aphanitic sandstones and breccias, limestones	Permo-Carboniferous.
Unconformity	Tuhuan folding, with granitic intrusions	Devonian.
Batonian	Absent in Southland	Silurian.
Manapourian	(4.) Golden Ridge Series—Absent (3.) Preservation Inlet Series—Slaty argillites, greywackes, quartzites, and mica-schist	Ordovician.
	(2.) Maniototian—Schists, quartzites, and limestones	Cambrian.
	(1.) Dusky Sound Gneissic Series—Gneisses, schists, and limestones	Cambrian or older.

CHAPTER IV.

MANAPOURI SYSTEM.

HISTORICAL AND GENERAL.

THE Manapouri System includes the "crystalline schists" of Sir James Hector,* the base rock of which he described as consisting of foliated and contorted gneiss that, he thought, corresponded with Humboldt's "gneiss-granite" forming the core of the Andes of South America. It comprises the Manapouri System† of Captain Hutton (1885), which he afterwards (1899) abandoned in favour of his Wanaka System.‡ In 1910 Professor Park§ revived the Manapouri System of Captain Hutton; and the name "Manapouri," though not the most appropriate that could be found, is so well established in the literature of New Zealand geology that it may be allowed to stand.

The metamorphic rocks of Westland form the core of the Alps, and lithologically, and probably also in age, are closely related to the crystalline schists of Otago and Southland. They constitute the "Gneiss-granite Formation" of Sir Julius von Haast.‖

Professor S. H. Cox¶ divided the crystalline rocks of Westland into two groups, which he called the "Granite and granitic gneiss" group and the "Metamorphic rocks" group, the former being the base rocks. Mr. P. G. Morgan,** who continued the detailed survey of north Westland begun by Dr. J. M. Bell and Mr. C. Fraser, placed the crystalline rocks in the Arahura Series of Bell and Fraser, which he subdivided into: (1) Lower gneisses and schists; (2) mica-schists; (3) less altered greywackes and argillites.

In south-west Nelson the metamorphic rocks disappear below Silurian and Tertiary strata, but reappear to the north. In his report on the "Geology of Collingwood County" Professor Park (1889) divided the older Palæozoic rocks†† into three groups—viz., the Pikikiruna Series, Aorere Series, and Riwaka Series. In their report on the Parapara Subdivision of Collingwood County Dr. J. M. Bell‡‡ and others grouped all the gneisses, amphibolites, mica-schists, crystalline limestones, quartzites, and slates containing graptolites in one great formation, which they called the Aorere Series. The Aorere Series of Dr. Bell is the equivalent of the Arahura Series of Mr. Morgan and of the Manapouri System of Professor Park.

The subdivision of the Manapouri System is based partly on lithological and partly on palæontological grounds. Progressive metamorphism can be traced downwards, from the partially

* J. HECTOR: *Outline of New Zealand Geology*, pp. 84–85, Wellington, 1886.
† F. W. HUTTON: Sketch of the Geology of New Zealand, *Quart. Jour. Geol. Soc.*, p. 191, 1885.
‡ F. W. HUTTON: *Trans. N.Z. Inst.*, vol. 32, p. 183, 1900.
§ J. PARK: *The Geology of New Zealand*, p. 28, Christchurch, 1910.
‖ J. VON HAAST: *The Geology of Canterbury and Westland*, p. 252, Christchurch, 1879.
¶ S. H. COX: *Rep. Geol. Expl. during 1874–76*, p. 66, 1877.
** P. G. MORGAN: Geology of Mikonui Subdivision, *Geol. Bull. No. 6 (N.S.)*, p. 76, 1908.
†† J. PARK: *Rep. Geol. Expl. during 1888–89*, No. 20, p. 230, 1890.
‡‡ J. M. BELL and others: *Geol. Bull. No. 3 (N.S.)*, p. 33, 1907.

altered Lower Ordovician or Upper Cambrian argillites, &c., to the highly altered gneissic rocks of the Dusky Sound Series.

The Dusky Sound Series consists mainly of gneisses, schists, and limestones, and the Maniototian mainly of felsitic schist, mica-schist, and chlorite-schist. The slaty argillites (often graphitic), mica-schist, phyllite, and semi-metamorphic greywackes of the overlying graptolite-bearing series are almost indistinguishable from the similar rocks in central and north Otago usually referred to the Kakanui Series of Hector.

The total thickness of the three divisions of the Manapouri System as exposed at Dusky Sound is probably not less than 32,000 ft., and may possibly be much greater.

DISTRIBUTION.

The two lower divisions of the Manapouri System extend from the south side of Dusky Sound to the north of Caswell Sound. A gigantic split or prolongation of the diorite intrusion that occupies the main divide in Fiordland branches off at Mount Bradshaw and follows a northerly course to Dusky Sound, where it forms the main mass of Resolution Island. From there it pursues its northerly course from fiord to fiord, and reunites once more with the main diorite intrusion to the south of Milford Sound, thereby enclosing the metamorphosed divisions of the Manapouri System in a ring of diorite intrusives. The coastal diorite batholith lies between the Upper Manapouri schists and the Preservation Inlet argillites, which disappear to seaward to the south of Breaksea Sound.

Sir James Hector, Captain Hutton, and Professor Park always mapped the unknown country lying to the west of lakes Monowai, Manapouri, and Te Anau as Archæan. The present survey shows that the main divide from Preservation Inlet to the Darran Mountains is occupied by the diorites, diorite-gneisses, and granites of the Clinton River intrusive series of Late Palæozoic age. The granite-gneisses, crystalline schists, and limestones of the Manapouri System are now known to occupy a strip in the Sounds country less than twenty miles wide. They disappear six miles to the south of Milford Sound.

STRUCTURE.

The two lower Manapouri series dip westward—that is, away from the main diorite batholith at the head of the Sounds. They are arranged in a great monoclinal. In Westland the gneisses and schists of the Manapouri System dip to the east and to the west, forming a great anticlinal the axis of which is occupied by the Tuhuan granites. The Ordovician argillites at Preservation Inlet and Dusky Sound also dip to the westward.

AGE.

No organic remains have been found in the two lower divisions of the Manapouri System. The lenses of limestone that occur interbedded with the gneisses and schists of the Dusky Sound Series would suggest the former existence of calcareous organisms ; but this is pure surmise. The argillaceous and arenaceous sediments of which some of the schists were evidently composed have been so highly altered that all traces of organic life, if they ever contained any, are, so far as at present known, completely obliterated. To determine their age we must therefore fall back on the indirect, and not quite satisfactory, method of investigation.

At Preservation Inlet and Chalky Inlet there occurs a series of blue slates, graphitic slates, quartzites, altered sandstones, argillites, and mica-schist. In the blue slaty rocks Mr. A. McKay* discovered a number of graptolites that have been ascribed by Dr. T. S. Hall† to the lowermost stage (Lancefieldian) of Lower Ordovician. Of the three genera identified by him, *Clonograptus* and *Bryograptus* are regarded in western Europe as typical of the Tremadoc stage of the Upper Cambrian.

* A. McKay: *Mines Rep.*, C.-11, p. 35, 1896.

† T. S. Hall: On the Occurrence of Lower Ordovician Graptolites in Western Otago. *Trans. N.Z. Inst.*, vol. 47, pp. 410-11, 1915.

The strike of the graptolite-bearing slates at Preservation Inlet is N. 23° E. (true bearing), a course which would bring them to Anchor Island and west side of Resolution Island, at the entrance of Dusky Sound. At both Anchor Island and Facile Harbour, Resolution Island, there are blue slates, or slaty argillites, associated with mica-schist and altered greywacke. At Chalky Inlet the graptolite-bearing series occupies a belt five miles wide; and, as the distance from the place where they are last seen at Chalky Inlet to Anchor Island, at the entrance of Dusky Sound, is only fourteen miles or less, it is not unreasonable to identify the slaty rocks at these places with one another. Added to this, Mr. William Docherty (1895) reported the occurrence of graptolites in the blue slates at Facile Harbour*; but this has not yet been verified. Though disturbed by the diorite intrusion of Resolution Island, the westerly dip of the lower divisions would carry them below the Preservation Inlet argillites. The middle division is certainly Cambrian. The lower granite-gneiss series may be Cambrian or older.

ORIGIN OF METAMORPHISM.

The three divisions of the Manapouri group of rocks recognized by New Zealand geologists are distinct lithological units that everywhere show progressive and increasing metamorphism, from the unaltered argillites to the highly altered gneisses and schists of the lowest division. In Fiordland, Westland, and Nelson the lowest and mostly highly altered division rests on, and is intruded by, a granitic and dioritic intrusive complex. In central Otago only the middle and upper divisions are exposed at the surface, and nowhere are they in contact with intrusive plutonic masses. But the lowest division must exist in this area; and, as there is no other agency that would explain the metamorphism of the upper divisions, it may be surmised that the lowest division here, as elsewhere, has been invaded by an intrusive magma that still remains uncovered. The metamorphism of the Manapouri group is greatest in the division nearest the intruding complex.

It is generally assumed that the folding of these ancient rocks was directly responsible for the dioritic intrusions so commonly associated with them. But it is possible that the anticlinal arching of the Manapouri formations was brought about by the uprising of the vast dioritic batholith. Be that as it may, we cannot escape the conclusion that the metamorphism of the highly altered gneisses and crystalline schists of the lower Manapouri division was deep-seated, and mainly, if not entirely, caused by the high temperature of the plutonic magma. The fracturing and parallel arrangement of the constituent minerals, and other cataclastic effects, were evidently induced by deep-seated thermal metamorphism.

DUSKY SOUND SERIES.

The Dusky Sound Series is the equivalent of Mr. Morgan's "lower gneisses and schists" in Westland, and of Professor Park's Pikikiruna Series in Collingwood.

Character and Distribution.

The rocks comprised in this series consist mainly of alternating bands of gneiss, mica-schist, hornblende-schist, amphibolite, chlorite-schist and crystalline limestone. They extend from Dusky Sound to the north of Caswell Sound. Their separation from the less-altered Maniototo Series is based solely on lithological grounds

The schists are distinguished chiefly by the prevalence of rutile, epidote, and amphibole. The limestones occur in massive bands, are usually bluish-grey in colour, and in places are speckled with small scales of molybdenite. The prevailing gneiss is a typical hornblende-gneiss. Under the microscope this rock is seen to consist essentially of feldspar and hornblende. Quartz is usually

* Mr. Docherty was a well-known prospector who lived for over twenty years at Dusky Sound. He visited Preservation Inlet in 1895, and, on seeing the graptolites in the blue slaty argillites in the Morning Star Mine, reported to Mr. McKay that he had seen similar organisms in the blue slates at Facile Harbour. A fatal illness prevented his return to Dusky Sound.

present, but is never abundant; also biotite, rutile, epidote, chlorite, titaniferous magnetite, and apatite. The dominant feldspars are orthoclase and microcline. An acid plagioclase is always present, and where abundant the rock may be called a quartz-diorite-gneiss.

The origin of the schists and gneisses is obscure. Some of the former are probably altered sedimentaries, and most, perhaps all, the latter altered igneous rocks. The limestones are certainly aqueous, but whether they are of organic or of chemical origin is unknown.

Structure and Thickness.

The gneisses, schists, and limestones of this series are intruded by the granites and diorites of the main divide. They dip away from the intrusives at very high angles. Towards Mount Pender the angle of dip flattens to 40° or even less. The structure is a simple monoclinal tilted to the west. At the head of Dusky Sound the hornblende-gneiss and associated schists are intruded by numerous veins of granite, ranging from 1 in. up to 30 in. in thickness.* At Caswell Sound large angular blocks of limestone are entangled in the intruding diorite.

The westerly dip of the Dusky Sound Series is maintained for a distance of five miles; and if the average angle of dip be taken at 45° the thickness of the series cannot be less than 14,000 ft.

MANIOTOTO SERIES.

These are the mica-schist, chlorite-schist, and quartzite series of western Otago, of Shotover, Arrow, Matukituki, and Mount Alta Range in the Wanaka country. They constitute the foliated schists of Sir James Hector, the foliated and middle schists of Mr. McKay, and the middle division of Mr. Morgan's Arahura Series of north Westland.

Character and Distribution.

The rocks of this series as seen at Dusky Sound consist of alternating bands of mica-schist (often garnetiferous), chlorite-schist, and amphibole-schist, with which are associated subordinate bands of quartzite, quartz-schist, crystalline limestone, massive bands of felsitic schist, and schistose greywacke. They occupy a belt of country about six miles wide, extending from Mount Pender westward to Long Island. To the westward they show a decreasing degree of metamorphism. To the west of Acheron Passage they are intruded by a northerly prolongation of the diorites and intrusive gneisses of the Preservation Inlet area. In the main, this diorite complex lies between the Maniototian schists and the argillites of the Preservation Inlet Series. It extends to the north, and eventually joins the main diorite batholith to the south of Milford Sound. The thickness of the Maniototian schists as exposed between Mount Pender and the Acheron Passage is about 8,000 ft.

Structure.

The schists of this series dip to the west at angles that seldom exceed 45°, and apparently lie conformably on the gneisses and schists that border them to the east. At Lake Wakatipu the schists strike N.W.–S.E.; in the Shotover area, from N.N.W.–S.S.E. to N.–S.; and in the ranges between the head of the Arrow River and Wanaka country, N.–S. North of Mount Aspiring the mica-schists, chlorite-schists, and quartzites cross to the west side of the main divide, and to the north their strike conforms with the N.E.–S.W. course of the axial chain. The change of strike is a result of the syntaxial N.W.–S.E. and N.E.–S.W. folding.

General Petrology.

The mica-schists range, on the one hand, from sericite-schist in which the quartz laminæ are strongly developed to a sericite-schist in which the quartz laminæ occur in paper-like sheets or are altogether absent; or, on the other hand, from a normal mica-schist to a micaceous quartz-schist that may pass into a quartzite.

* S. H. Cox: *Rep. Geol. Expl. during 1877–78*, p. 11, 1879.

The sericite-schists always contain biotite, which in some bands almost wholly replaces the sericite. When examined under the microscope both the sericite-schists and biotite-schists are seen to contain much rutile in well-defined needles, a little chlorite as scales and fibres, a few plates of an acid plagioclase, and often zoisite, epidote, and calcite as alteration products of the feldspar. In some bands the sericite-schists and biotite-schists are speckled with grains and well-developed crystals of red garnets that range up to 2 mm. in diameter, and fine grains of magnetite. The garnetiferous rocks may be called garnet-mica-schist

The chlorite-schists range from pale to dark green in colour. Magnetite is nearly always present, and often some biotite. Under the microscope sections of chlorite-schist show chlorite and quartz, with rutile, titanite, magnetite, and a little plagioclase. Calcite and epidote, though not abundant, are seldom altogether absent.

The amphibole-schists occur in thin bands in the mica-schist. They are composed of quartz laminæ separated by thin layers of amphibole. In some bands the quartz is almost entirely replaced by tremolite, forming a pale-green fissile rock that may be called tremolite-schist. Thin bands of talc-schist with abundant magnetite occur on Mount Pender.

The feldspathic schists are coarse-grained rocks with partings of biotite or chlorite. Under the microscope they are seen to be composed of a mosaic of quartz grains, orthoclase, and plagioclase set in a matrix of biotite, chlorite, epidote, and rutile, with calcite, zircon, magnetite, and pyrite as accessory minerals.

In these schists there occur seven thin, heavily mineralized, quartzose bands containing nests of chalcopyrite, pyrites, and pyrrhotite, with which are associated quartz, orthoclase, hornblende, garnets as well-developed crystals and thin veins of massive garnet rock, biotite, sericite, lepidolite, fuchsite, epidote, magnetite, hæmatite, molybdenite in large plates, graphite in thin scales, ouvarovite, and vesuvianite, this last in large fine crystals ranging up to 1 in. in length and ½ in. in diameter. In some bands epidote is so abundant as to form a rock that might be appropriately called epidote-schist.

Foliation and Origin of Schists.

The planes of foliation of the mica-schists coincide with the changes of lithological character of the constituent beds or layers, and from this it is inferred that they coincide with the bedding-planes of the original sediments. The mica-schists are evidently altered argillaceous and arenaceous rocks; and the chlorite-schists, altered sills or lavas of a basic character.

PRESERVATION INLET SERIES.

This series is the equivalent of the Kakanui Series of Sir James Hector, the upper division of the Arahura Series of Dr. Bell and Mr. Fraser as defined by Mr. Morgan, and the Aorere Series of Professor Park. It consists mainly of slaty argillites and schistose greywacke, the latter usually designated by Mr. McKay "semi-metamorphic schist." Associated with these are bands of phyllite, mica-schist, quartzite, and crystalline limestone. The slaty rocks are in many places carbonaceous or graphitic. In 1873 Sir James Hector mapped the argillites at Preservation Inlet and Resolution Island as Older Palæozoic.

Distribution and Structure.

In Fiord County, and generally throughout Southland, Otago, Westland, and Nelson, the Kakanuian rocks are conformable to the underlying Maniototian. The line of demarcation between the two formations is quite arbitrary, but there is no difficulty in recognizing them in the field, as the older series consists essentially of highly altered rocks and the younger series of unaltered or only partially altered sediments.

In the Dusky Sound and Preservation Inlet areas the Ordovician rocks dip to the west at high angles—that is, away from the diorites and gneisses by which they are intruded, and which separate them from the Maniototian schists. At Preservation Inlet and Chalky Inlet they strike about

N.W.–S.E. (mag.), and at Resolution Island, Dusky Sound, N. 10° E. (mag.). This difference of strike, amounting to nearly 50°, in conjunction with their angle of dip, which is steeper than that of the underlying series, might be held to be an evidence of unconformity. But at Preservation Inlet the Ordovician rocks have been intruded by a long batholith of granite. They dip away from the intrusive mass, and it is evident that the direction of the intrusion determined the strike of the clastic formation. The thickness of the Preservation Inlet Series as exposed at Dusky Sound is 10,000 ft. or more.

Age.

Dr. T. S. Hall,* who examined a collection of graptolites from Preservation Inlet, has stated that the fossils clearly belong to the series known as Lancefieldian in Victoria, which is very low down in the Ordovician. The forms he recognized are *Clonograptus tenellus* Linnarson ; *Clonograptus tenellus* var. *callavei* Lapworth ; *Clonograptus* sp. nov. ; *Bryograptus* sp. ; *Tetragraptus decipiens* T. S. Hall.

In Europe and America the genus *Clonograptus* is not known in the Ordovician, but is regarded as characteristic of the Upper Cambrian. Whether the graptolite-bearing horizon of Preservation Inlet Series should be referred to the Upper Cambrian or to the lowest Ordovician is perhaps not of great moment.

The fossiliferous horizon of the Golden Ridge Series, north Nelson, contains a large and varied assemblage of graptolite forms, none of which are found at Preservation Inlet. According to Dr. Hall† the Golden Ridge graptolites belong to the Bendigonian stage of the Lower Ordovician.

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* T. S. Hall: *Trans. N.Z. Inst.*, vol. 47, pp. 410–11, 1915.

† T. S. Hall: *loc. cit.*, pp. 411–13, 1915.

CHAPTER V.

MAITAI SYSTEM.

HISTORICAL AND GENERAL.

The Maitai System 'as now defined includes the Te Anau Series and Maitai Series of Sir James Hector (1876 and 1886), which certainly belong to the same formation. They are indistinguishable in the field, and have always been grouped together by Captain Hutton, Mr. McKay, and Professor Park.

CHARACTER OF ROCKS AND DISTRIBUTION.

In the Waiau country these rocks consist of alternating argillites and greywackes, with which are associated bands of red argillite, green aphanitic sandstones and breccias, and red or purple aphanitic breccias. In the Bryneira Range, north of the Hollyford Valley, thin beds of argillite alternate with thin beds of crystalline limestone.

The rocks of the Maitai Formation form the Longwood Range, Takitimu Mountains, and western part of the Livingstone Mountains.

STRUCTURE.

In the Longwood Range and Takitimu Mountains the argillites, greywackes, and associated rocks are folded in a N.W.–S.E. direction, and are arranged in anticlinal and synclinal folds. In the Livingstone Mountains the strike of the rocks is more northerly. It is noteworthy that, though the general trend of the Longwood and Takitimu chains is north and south, the rocks composing these mountains are folded in a N.W.–S.E. direction.

THICKNESS.

In the Longwood Range the Maitai rocks are so disturbed and broken by igneous intrusions that it is difficult to make even an approximate estimate of their thickness. But in the Takitimu Mountains, though igneous intrusions are rare, the rocks are intersected by so many faults that it is difficult to arrive at a satisfactory estimate of their thickness. Probably 7,000 ft. is not in excess of the actual thickness.

AGE.

Except some indistinct plant-remains contained in the argillites, this pile of sedimentary strata appears to be barren of organic remains.

In the country north-east of Lake Te Anau and in the Bryneira Range the Maitai Formation rests on the Kakanuian (Hector); and the absence of the Silurian (Batonian Series) would indicate a considerable unconformity between them. Of this unconformity there is, however, not much physical evidence, as both formations are involved in the same system of folding. North-east of Mount Hamilton the Maitais are overlain by marly shales that belong to the upper part of the Trio-Jurassic Hokonuian. But here also the Maitai and Hokonui formations take part in the N.W.–S.E. folding of the Hokonuian movement that, as already described, was syntaxial with the N.E.–S.W. Rangitatan folding of the axial chains.

In the Dun Mountain - Wairoa area in Nelson, where the Maitai rocks are typically developed, the Maitai limestones contain a large bivalve shell with a prismatic structure that was at one time referred, with some reservation, to the genus *Inoceramus*. Mr. C. T. Trechmann,* who has examined many examples of this peculiar fossil, is of the opinion that it belongs to the Myalinid genus *Aphanaia*, a few species of which have been described by de Koninck from the Permo-Carboniferous of Australia and New Caledonia.

Besides *Aphanaia*, Mr. Trechmann identified, among the collections of fossils from the Maitai limestone, *Platyschisma* sp., *Pleurotoma* or *Mourlonia* sp., *Strophalosia* sp. (*Productus* of Hector), *Rhynchonella* (? *pugnax*) cf. *pleurodon* Phill., *Martinia* (*Martiniopsis*) *subradiata* G. Sow. (*Spirifer glaber* of Hector), *Spirifer* cf. *bisulcatus* J. Sow.; also the coral *Zaphrentis* sp., and a tubular organism that suggests the tubular structures called *Torlessia McKayi* Bather† (from the Mount Torlesse Annelid beds), and the *Serpulites Warthi* of Waagen.

Generally, these fossils suggest that the Maitai Formation is Permo-Carboniferous; and, as the lowest fossiliferous horizon of the Hokonuian is not older than Middle Triassic age, the palæontological evidence would indicate a considerable hiatus between the Maitai and Hokonui formations.

NOTE.—In continuation of the present survey, in February, 1921, the author crossed the ranges lying between Lake Wakatipu and Glade House at the head of Lake Te Anau. In the course of this journey he examined the Greenstone Valley and traversed the Livingstone Range between the Greenstone Saddle and a point opposite the lower end of Lake Gunn, and the Darran Range between the sources of the Murcott Burn and Waterfall Creek. At the north end of the Livingstone Range fossils were discovered in a band of gritty limestone interbedded with pale-green and blue fissile argillites. The forms identified included *Productus*, *Spirifer*, *Spiriferina*, a *Turbo*-like gasteropod, and two corals. At the mouth of Falls Creek in the same district Mr. G. M. Moir, M.Sc., discovered on the weathered surface of a green argillite good examples of a tube-like organism that resembles *Torlessia McKayi* Bather. Similar fossils were also found by the author in the same rocks on the Livingstone Range opposite the middle of Lake Gunn. Here the argillites are associated with thin bands of grey limestone. It is of interest to note that in his progress report, 1890-91, page xlv, Sir James Hector mentions the occurrence of Permian fossils to the west side of Lake Harris in dark-coloured argillaceous sandstones, underlain, according to McKay, by grey flaggy limestones that correspond to the Maitai limestone. These limestone bands extend south to the Livingstone Range.

IGNEOUS INTRUSIONS.

Along the east side of the Bryneira Range the silvery-grey schists of the Maniototian abut against the Permo-Carboniferous Te Anau - Maitai rocks along the line of a great fault. On the course of this fault the younger formation is intruded by a series of rocks ranging from intermediate to ultra-basic. The diorite, dunite, and serpentine at Hidden Falls Saddle were discovered by Professor Park‡ in 1886. In addition to these rocks, Dr. P. Marshall§ twenty years later described gabbro, pyroxenite, and lherzolite, and noted the increasing basicity from west to east.

At the south end of the Takitimu Range, along the boundary of the Tertiary coal-measures to the north of the Ohai Valley, the Permo-Carboniferous rocks are intruded by a massive dyke of augite-porphyrite. At the south end of the Longwood Range, besides the granite, diorite, and gabbro intrusions to which reference is made in Chapter VI, the Maitai argillites are intruded by dykes of basalt and melaphyre, technical descriptions of which are given by Mr. R. A. Farquharson.||

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* C. T. TRECHMANN: The Age of the Maitai Series of New Zealand, *Geol. Mag. (N.S.)*, dec. vi, vol. 4, pp. 53–64, 1917.

† The Mount Torlesse Annelid, *Geol. Mag.*, dec. v, vol. 2, pp. 532–41, 1905.

‡ J. PARK: On the Country between the Dart River and Big Bay, *Rep. Geol. Expl. during 1886–87*, pp. 121–37, with map and sections, 1887.

§ P. MARSHALL: Geological Notes on the Country North-west of Lake Wakatipu, *Trans. N.Z. Inst.*, vol. 38, pp. 560–67, 1906.

|| *Trans. N.Z. Inst.*, vol. 43, pp. 448–82, 1911

RELATIONSHIP OF NEW ZEALAND TO GONDWANALAND.

Throughout the Devonian movement New Zealand, in common with a large part of Australia and northern India, was dry land. Of the Middle Devonian transgression of the sea, that left richly fossiliferous sediments in the northern Shan States and other parts of Asia, there is no trace in New Zealand.

Towards the middle of the Carboniferous period there took place throughout Eurasia a great orogenic movement, during which the Lower Carboniferous strata were removed over wide areas by subaerial denudation. Hence it has come about that, except in the areas where there was continuous deposition, there is a well-marked stratigraphical break at the base of the Upper Carboniferous strata, which in most northern regions rest directly on the Older Palæozoic rocks.

Except perhaps on the east coast of Australia, where Carboniferous strata occur, the main mass of that continent and the whole of the New Zealand area remained as dry land till the close of the Carboniferous, when there began a great marine transgression that affected Australia, India, and South Africa, and continued into the Permian period. This submergence was accompanied by many minor transgressions and recessions of the sea; and as a consequence of these there was laid down a vast pile of alternating fresh-water and deltaic beds, here and there intercalated with marine sediments.

The Permo-Carboniferous marine faunas of Australia and New Zealand are closely related; but the New Zealand flora of that period is unknown, which may suggest that this area was completely submerged. Many of the New Zealand Permo-Carboniferous strata are evidently deltaic; and in these there may yet be found the remains of the flora of the land that furnished the sediments of these beds. New Zealand has furnished no Palæozoic plants,* and no trace of the fern-like *Glossopteris*, which is the most numerous and characteristic fossil of the "southern" or *Glossopteris* flora, a plant not met with in the normal fossil flora of the northern lands.

The remarkable similarity of the Permo-Carboniferous fossil floras of South Africa, India, and Australia has led to the suggestion that these lands, now so widely separated, were at this time united by direct land connections, and formed parts of a continent that occupied a part of what is now the Indian Ocean. This hypothetical continent has been called Gondwanaland. The absence of *Glossopteris* in the Permo-Carboniferous rocks of New Zealand may suggest that this area did not form a part of the ancient Gondwanaland in the Late Palæozoic period; but the character of the sediments and the presence of the glacial beds recently discovered by Professor Park† on the east coast of Otago would lead to the conclusion that it formed part of a large land-mass lying not far from the shores of Gondwanaland.

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* E. A. Newell Arber: *Pal. Bull. No. 6*, N.Z. Geol. Surv., p. 20, 1917.
† J. Park: *Trans. N.Z. Inst.*, vol. 52, pp. 107–8, 1920.

CHAPTER VI.

CLINTON RIVER INTRUSIVE SERIES.

GENERAL CHARACTER AND DISTRIBUTION.

The Clinton River intrusives occupy the main divide from Preservation Inlet to the Hollyford Valley. For a distance of over a hundred miles they lie between the granite-gneisses and schists to the west and the Permo-Carboniferous argillites and greywackes to the east; and prolongations extend northward from the Darran Mountains to the Bryneira Range, and eastward to the Longwood Range, the Bluff, and Stewart Island. A branching arm extends from Dusky Sound to Milford Sound, and envelopes the lower divisions of the Manapouri System.

The commonest rock of the series is a medium- to coarse-grained hornblende-diorite, in which the ferro-magnesian mineral and feldspar are strongly developed. Pyroxene is often present; and it is evident that in some cases the hornblende has developed from augite. Quartz is not common. Towards the borders of the batholith the diorites of the oligoclase-andesine phase pass into basic diorites of the labradorite-anorthite or gabbro type. Another phase is dominated by alkali feldspars, without or with quartz, as in granulites and granites.

In the middle and upper parts of the Clinton Valley and in the Arthur Valley the diorite as seen in mass often exhibits a rudely gneissoid structure, and internally there is often evidence of compressive stress. In many places the rock is intersected by a network of small and large veins of quartz that occupy tensional rents probably formed by some movement after complete consolidation. Pegmatite veins are common in the granites south of Lake Manapouri, and aplite dykes occur in the serpentine of Milford Sound. Intrusive gneisses and hornblende rock occur at McKinnon's Pass. Dykes of camptonite intrude the granite at Preservation Inlet, and mica-norite in the Darran Mountains; and dykes of basalt and augite-porphyrite invade the argillites of Longwood Range and Takitimu Mountains.

Succession of Intrusions.

As already mentioned, the diorites intrude the gneisses and schists of the Manapouri Formation to the west, and the unaltered Permo-Carboniferous rocks to the east. At Preservation Inlet the diorites are intruded by granite, and at Milford Sound by dunite. In the Darran Mountains they pass into a mica-norite; and farther north, in the Bryneira Range, norite is associated with gabbro and serpentine.

The conclusion arrived at is that, in accordance with some process of magmatic differentiation, the series began with the intrusion of a magma of average composition, and passed in successive phases from the more siliceous readjusted magmas to those low in silica. In other words, the series began with a mean magma and ended with extremes.

AGE OF INTRUSIONS.

The diorites and granites have intruded the Permo-Carboniferous rocks of the Longwood Range; therefore the date of intrusion must be later than that period. And, as boulders of

VIEW LOOKING UP CLINTON VALLEY FROM HEAD OF LAKE TE ANAU.

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diorite, granite, and gneiss are abundant in the conglomerates of the Trio-Jurassic formation occupying central and south-east Southland, we must conclude that the date of intrusion took place at the close of the Permian, or, at the latest, early in the Trias.

The date of the dunite intrusions cannot be arrived at with any degree of certainty. At Hidden Falls Saddle, on the east side of the Bryneira Range, Permo-Carboniferous rocks are intruded by dyke-like masses of norite, gabbro, and serpentine; in north Westland the Pounamu Series of altered olivine, serpentine, and allied ultra-basic rocks occurs as sheets and sills intruding the Arahura gneisses and schists of Cambrian age; and at Dun Mountain dunites and serpentine intrude the Permo-Carboniferous Maitai Formation. Nowhere in the South Island, so far as known at present, are strata younger than Permo-Carboniferous intruded by rocks of the ultra-basic series. But at Wade, north of Auckland, argillites generally believed to belong to the Trio-Jurassic formation are intruded by a dyke or sill of serpentine.

Dunite and serpentine do not appear as detrital material anywhere in New Zealand till the conglomerates at the base of the Oamaruian of Miocene age is reached. The serpentine intrusion at Wade is probably post-Jurassic and pre-Miocene.

The absence of dunite and serpentine in the Triassic rocks of Nelson cannot be regarded as certain evidence that the date of intrusion was post-Triassic. The Triassic conglomerates of Nelson contain a series of crystalline eruptive rocks derived from the Pikikiruna Range. Clearly, the ancient Triassic shore-line lay to the north-west; and, as the Trias formation rests on the Maitais, it is clear that these rocks and their associated sills of dunite and serpentine formed a part of the sea-floor on which the Trias sediments were deposited. The dunites and serpentines of the South Island are post-Permo-Carboniferous, and may very well be pre-Triassic.

Sir James Hector always recognized the intrusive character of the dioritic complex, but did not know that the dioritic rocks occupied so much territory. In his geological map of 1873 he shows the diorites as intrusive in the argillites and greywackes of the Longwood Range.

PETROLOGY.

The dominant type of rock as exposed in the Clinton-Arthur Valley section is a normal hornblende-diorite, ranging from medium to coarse grained in texture. On weathered surfaces the feldspar is partially kaolinized, and the dark-green hornblende, which is always prominent, usually stands out in clear relief. As a rule the feldspar and hornblende occur in about equal amount, but in some bands the hornblende predominates to such an extent that when seen in mass the rock resembles a dense black amphibolite. In the lower Clinton, at Mount Edwards, and the east end of the Darran Range the hornblende is accompanied by much pyroxene, occasionally to the exclusion of the former, the rock passing into pyroxene-diorite. In other bands the hornblende is accompanied by a small amount of biotite.

Hornblende-diorite.—This is the typical rock of the diorite series. It forms the walls of the Clinton and Arthur cañons, and the main mass of the mountains to the north and south.

Macroscopically the prominent grey feldspar and hornblende minerals impart a granitoid appearance to the rock, which generally is hard and not much jointed.

In thin slice, under the microscope, the rock is seen to be a holocrystalline aggregate of feldspar and hornblende, with magnetite, apatite, sphene, calcite, and sometimes quartz as accessory minerals. An orthorhombic pyroxene is sometimes present.

The plagioclase occurs in large plates, as a rule without well-defined boundaries; highly twinned on the albite law, with occasionally fine examples of pericline twinning; mostly oligoclase and labradorite or andesine; often decomposed to kaolin and calcite.

The hornblende is abundant, with ragged outlines; colour, usually yellowish-green; shows alteration to a product resembling chlorite with magnetite inclusions; high birefringence and refractive index; usually allotriomorphic.

Analysis by Otago School of Mines.

	Per Cent.
Silica (SiO_2)	54·88
Alumina (Al_2O_3)	17·58
Ferric oxide (Fe_2O_3)	2·72
Ferrous oxide (FeO)	3·93
Titanium oxide (TiO_2)	0·85
Manganous oxide (MnO)	0·12
Calcium oxide (CaO)	8·31
Magnesium oxide (MgO)	4·80
Potassium oxide (K_2O)	1·39
Sodium oxide (Na_2O)	3·36
Water lost below 100° C.	0·15
Water lost above 100° C.	1·47
Phosphorus pentoxide (P_2O_5)	0·18
Carbon dioxide (CO_2)	None
Sulphur	0·10
	99·84

The rock also contains traces of barium and strontium oxides.

Quartz-biotite-diorite.—This rock is fairly common in the upper Clinton Valley, and may be a later intrusion than that of the hornblende-diorites.

Macroscopically this is a medium-grained rock, in which the feldspars and hornblende are easily recognizable.

Microscopically the rock is seen to be composed of plagioclase and hornblende, with smaller amounts of biotite and quartz. Epidote and sphene occur as accessory minerals, and a few grains of secondary pyrites.

The plagioclase is probably andesine, much twinned on the albite law. The hornblende is green, and shows decomposition to a chloritic product and magnetite.

The relative proportions of soda and lime show that the plagioclase is mainly andesine, with perhaps some labradorite. The results of an analysis of this rock made by the Government Analyst are given below:—

Analysis of Quartz-biotite-diorite.

	Per Cent.
Silica (SiO_2)	55·92
Alumina (Al_2O_2)	19·34
Ferric oxide (Fe_2O_3)	0·93
Ferrous oxide (FeO)	4·55
Titanium oxide (TiO_2)	1·12
Manganous oxide (MnO)	0·18
Calcium oxide (CaO)	7·49
Magnesium oxide (MgO)	3·62
Potassium oxide (K_2O)	1·46
Sodium oxide (Na_2O)	3·56
Water lost below 100° C.	0·18
Water lost above 100° C.	1·22
Phosphorus pentoxide (P_2O_5)	0·36
Carbon dioxide (CO_2)	None
Sulphur	0·18
	100·11

Pyroxene-diorite.—This rock occurs as boulders among the gravels of the lower Clinton River.

Macroscopically it is a medium-grained grey rock, speckled with partially kaolinized feldspar and dark-green hornblende.

Microscopically the rock is composed of plagioclase, mostly labradorite and andesine, finely twinned after the albite and Carlsbad laws; hornblende in green and idiomorphic crystals; augite in irregular crystals, often changed to uralite; with apatite, sphene, and magnetite as accessory minerals, and epidote, chlorite, calcite, and iron oxide as secondary products.

An augite-diorite, or gabbro, occurs in the floor of the Round Hill sluicing claim, at the south end of the Longwood Range. It has been described by Mr. R. A. Farquharson, M.Sc., who states that it consists essentially of plagioclase, augite, and hornblende. The augite in some cases seems to take the form of diallage. The plagioclase is regarded as almost pure anorthite.

The percentage of silica is as low as in a normal gabbro. The general composition of the rock indicates that the feldspar is probably labradorite, not anorthite, as supposed by Mr. Farquharson. His analysis* is as follows:—

	Per Cent.
SiO_2	47·40
FeO	6·60
Al_2O_3	18·17
CaO	12·23
MgO	7·17
K_2O	0·20
Na_2O	2·75
H_2O	0·75
Fe_2O_3	5·42
MnO_2	Trace
TiO_2	Trace
	100·69

Gabbro.—A boulder in the drift at the mouth of the Cleddau River. A coarse-grained dark-grey rock.

Macroscopically this rock showed feldspar, hornblende, augite, and biotite.

Microscopically the plagioclase, which is probably labradorite, showed fine twinning on the albite law. The ferro-magnesian minerals are abundant, and show ill-defined boundaries. The analysis of this rock by the Government Analyst shows the composition of a normal gabbro.

Analysis of Gabbro.

	Per Cent.
Silica (SiO_2)	46·74
Alumina (Al_2O_3)	18·90
Ferric oxide (Fe_2O_3)	5·18
Ferrous oxide (FeO)	6·25
Titanium oxide (TiO_2)	1·26
Manganous oxide (MnO)	0·12
Calcium oxide (CaO)	10·01
Magnesium oxide (MgO)	5·60
Potassium oxide (K_2O)	1·82
Sodium oxide (Na_2O)	2·38
Water lost under 100° C.	0·12
Water lost over 100° C.	1·14
Barium oxide (BaO)	0·10
Strontium oxide (SrO)	0·10
Carbon dioxide (CO_2)	None
Sulphur	0·05
Phosphorus pentoxide (P_2O_5)	0·65
	100·42

Biotite-norite.—This rock forms a large boss-like mass at the east end of the Darran Mountains, at the sources of the Cleddau River.

Macroscopically it is a dark-grey granitoid rock of medium texture, in which feldspar and sometimes flakes of biotite are conspicuous.

Microscopically the rock consists of plagioclase, hypersthene, and biotite. The plagioclase occurs as large plates, well twinned on the albite law, often kaolinized; and as small idiomorphs in

* R. A. Farquharson: The Platinum Gravels of Orepuki, *Trans. N.Z. Inst.*, vol. 43, p. 465, 1911.

the ground-mass, well twinned and fresh. The extinction angle indicates a basic variety, probably labradorite.

The hypersthene is abundant as irregular plates and grains, with schiller structure well developed; alteration to a serpentine product is common. The biotite occurs in large irregular plates, and is often altered to a chloritic mineral enclosing magnetite.

Biotite-granite.—At the south-east end of Longwood Range, on the west side of Pourakino Creek, which flows into Jacob's Estuary, a large batholith of granite intrudes the argillites of the Maitai Formation.

Macroscopically the rock is grey in colour and from fine to medium grained in texture.

Microscopically the essential constituents are orthoclase and microcline, quartz and biotite, for the most part hypidiomorphic. The biotite is not abundant, and in some places is rare. It as a rule shows alteration to a chloritoid product and magnetite. Among the accessory minerals in the rock are apatite and sphene.

Granite.—Intruding the Ordovician slaty argillites at Preservation Inlet there is a mass of coarse-grained pink granite with conspicuous feldspars.

Microscopically the rock is composed of orthoclase and oligoclase in about equal amount, quartz, and biotite.

Granulite.—A massive boss of this rock is intruded by the dunite and serpentine at Anita Bay, Milford Sound.

Macroscopically the rock is fine-grained and granular, and contains little or no ferro-magnesian mineral.

Microscopically it consists of an intimate mixture of orthoclase and quartz, which has derived its granular texture from the simultaneous crystallization of these constituents.

In texture and composition the rock varies considerably, this arising from the varying proportions of the feldspar and quartz. This mass of granulite (aplite) is of unusual size for a rock of this type. It is probably an acid segregation from the original dioritic magma. The composition of what appeared to be an average sample is shown by the following analysis by the Government Analyst:—

Analysis of Granulite.

	Per Cent.
SiO_2	75·62
Al_2O_3	13·23
Fe_2O_3	0·65
FeO	0·21
TiO_2	0·10
MnO	Trace
CaO	1·56
MgO	0·16
K_2O	5·73
Na_2O	2·48
H_2O lost under 100° C.	0·20
H_2O lost above 100° C.	0·34
P_2O_5	Trace
CO_2	None
S	None
	100·28

Ultra-basic Intrusives.—Intrusive masses of dunite, and of dunite altered to serpentine, occur at Anita Bay, Milford Sound; at the Hidden Falls Saddle and Olivine Range, to the north of the Hollyford Valley; and at Red Hill, to the east of Big Bay. With these masses are associated bowenite, harzburgite or saxonite, lherzolite, and pyroxenite. Mineralogical descriptions of some of these rocks have been given by Professor Ulrich, Dr. Marshall, and Professor

PLATE VI.

Mount Balloon from Top of McKinnon Pass.

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Park; but such descriptions are not of much value unless accompanied by the chemical analysis of typical examples. As the analyses are not yet available detailed reference to these intrusions will be given later.

McKinnon's Pass.

On the summit of the pass there is a small lens of gneisses and hornblende rock, usually well foliated. At the outcrop the constituent feldspars are much decomposed, and in consequence of this the gneisses are generally soft and friable. The pass owes its existence to the circumstance that the gneisses are less resistant than the neighbouring diorites forming Mount Balloon and Mount Hart.

A whitish-grey rock from the pass, that as seen in place resembles a foliated micaceous quartzite, is found to be, when examined in thin slice, a fine-grained mica-gneiss composed of microline and plagioclase, muscovite, biotite, abundant quartz, sphene, and epidote. This is (M 1) described by Mr. Speight (1910). With this rock is associated a diorite-gneiss, often well foliated and usually much decomposed at the surface. Under the microscope this rock is seen to consist of plagioclase (mostly oligoclase), hornblende, biotite, a little muscovite, quartz (usually abundant), an occasional garnet, with rutile, and titanite. This rock has also been described by Mr. Speight (1910). With it is associated a heavy black foliated rock, in which hornblende is conspicuous in hand-specimens. In thin section this rock is seen to be mainly composed of brownish-green hornblende and a little plagioclase; there are also present hypersthene, diallage, and some olivine. Dr. Marshall (1907) has described this rock as a wehrlite. In the foliated diorite-gneiss there are basic segregations composed mainly of hornblende with usually a little muscovite, abundant epidote, and a few grains and needles of rutile. This is apparently the amphibolite of Mr. Speight (1910). These gneissic rocks are intrusives, and all exhibit the effects of intense compressive stress.

The Sounds Area.

In 1905 Dr. P. Marshall* described the dunite and associated rocks discovered in 1863 by Sir James Hector at Anita Bay, Milford Sound. Two years later he published a petrological description of the pink granite at Preservation Inlet, of gneisses from Dusky Sound and Milford Sound, and of hornblende-schists from Doubtful Sound and Thompson Sound.† In 1910 Mr. R. Speight,‡ in a suggestive paper on the geology of the West Coast Sounds, published a description of granites, gneisses, diorites, and various schists from Preservation Inlet, Dusky Sound, Dagg's Sound, Thompson Sound, George Sound, Bligh Sound, Milford Sound, and McKinnon's Pass. As the result of his petrological examinations he concluded that these rocks are in all probability not truly Archæan, but are metamorphosed igneous rocks, with perhaps occasional metamorphosed sedimentaries. This conclusion he based on the following evidence (*l.c.*, p. 259):—

"(1.) The rocks never appear to exhibit that profound metamorphism which characterizes most Archæan rocks.

"(2.) Frequently the only sign of metamorphism is the presence of strain and cataclastic effects; gradations in these can be traced from rocks practically without them to those which exhibit them to a marked degree.

"(3.) The rocks do not show the effects of heat on their mineralogical character, as they would if they were truly Archæan and had experienced subcrustal changes. They belong to the upper or middle zone of Grubenmann.

"(4.) Rutile is a prominent constituent of the rocks, and this suggests that some may be altered sedimentaries. Mica-schists, however, are seldom met with."

* P. Marshall: Magnesian Rocks at Milford Sound, *Trans. N.Z. Inst.*, vol. 37, pp. 481–84, 1905.
† P. Marshall: Geological Notes on the South-west of Otago, *Trans. N.Z. Inst.*, vol. 39, pp. 496–503, 1907.
‡ R. Speight: Notes on the Geology of the West Coast Sounds, *Trans. N.Z. Inst.*, vol. 42, pp. 255–67, 1910.

A wide band of diorite-gneiss, the "syenite" of McKay, extends from Preservation Inlet to Dusky Sound, where it is well exposed at Pickersgill Harbour and some of the small islands lying to the north of this. Both to the east and west of this rock, and apparently closely associated with it, there are parallel bands of true gneiss, the "granite-gneiss" of Sir James Hector. These intrusive gneisses occupy a large part of Resolution Island, and thence extend to the north. At Dusky Sound this intrusive complex lies between the Maniototian schists to the east of the Acheron Passage and the slaty argillites of the Preservation Inlet Series to the west of Resolution Island. To the east, the Acheron Passage, which appears to be a down-faulted strip, or graben, forms approximately the boundary of the intrusives. To the west the argillites and mica-schists are much disturbed, and dip away from the intrusive—that is, seaward—at high angles.

CHAPTER VII.

TERTIARY GEOLOGY.

MIOCENE OAMARUIAN SYSTEM.

Conditions of Deposition.

During the Miocene submergence the greater part of Otago and Southland became covered with a thick sheet of fresh-water, deltaic, and marine sediments. The deltaic sediments accumulated faster than the rate of sinking; and on their emergent surface there grew a dense vegetation, composed mainly of forest-trees (among which the pines were abundant), palms, ferns, and mosses. In the course of time, perhaps some thousand years or more, the growth and decay of the vegetation formed thick beds of peaty matter along the seaboard, which gradually receded as the sea slowly transgressed on the land.

After the deposition of the fresh-water and deltaic beds, which, with their intercalated seams of lignite and brown coal, comprise what are called the Oamaruian coal-measures, the submergence became more rapid, and in consequence of this the coal-bearing beds became covered with clays, sands, and calcareous sediments. These last were composed mainly of Polyzoa and marine shells, and now form the thick beds of limestone seen at Clifden, Sharpridge, Dipton, Castle Hill, Winton, and other parts of Southland.

The calcareous sediments were followed by marine sands and clays; and these are the upper, or closing, members of the Middle Tertiary formation in Southland.

At the close of the Miocene the New Zealand area consisted of an axial chain of low relief, here and there breached by sea-passages and fringed in places with small islands. The Miocene land area was smaller than the present, and surrounded by a warm, semi-tropical, shallow sea, on the floor of which rested the marginal sheet of sediments just described.

With the advent of the Pliocene there began a series of crustal movements that was destined to bring about great geographical changes throughout the whole of New Zealand. The downward movement was arrested, and immediately followed by uplift. This uplift of the land was general, but more rapid along the axial chains than towards the coasts. The surrounding seas were shallow, and as a first consequence of the uplift the sheet of Miocene sediments became dry land. The upward differential movement soon arched the region along the axial chains; and this introduced enormous crustal stresses, which found relief by the formation of numerous faults and dislocations that traversed the base rocks on which the covering sheet of Miocene strata rested.

Along the seaboard, where the upward movement was least, strips of the Miocene beds remained almost undisturbed; but towards the interior highlands, where the uplift was greatest, strips and patches of these strata became entangled in fault-troughs and along fault-planes. While this crustal dislocation was in progress subaerial denudation was extremely active. The Pliocene was a period of heavy rainfall, and it was not long till the weak, unconsolidated, newly uplifted Miocene beds were almost completely removed from the higher lands. It was only where they lay in protecting troughs or montane basins that they escaped destruction; and even in these they were frequently tilted and crushed by the faultings that were the cause of their survival.

In the differential Pliocene uplift which gave New Zealand its present form we have the explanation of the numerous coastal and valley strips, montane basins, and faulted patches of the Middle Tertiary coal-bearing formation that abound throughout the Dominion.

Distribution.

The Tertiary coal-bearing formation extends from the shores of Te Waewae Bay northward along the floor of the Waiau Valley to Lake Te Anau. It forms the eastern shores of that lake till Welcome Point is reached, to the north of which it occupies both shores as far as Worsley Arm. In a distance of eighty miles this strip of Tertiaries ranges from two or three miles to twenty-four miles in width. From Mount Linton a band of the coal-measures extends eastwards through the gap between the Longwood Range and Takitimu Mountains to Nightcaps, forming the Ohai and Wairio coalfields. From Nightcaps the coal-measures extend to the south and east below the Aparima Plains.

Character of Beds, and Thickness.

The Middle Tertiary beds range from conglomerates and gritstones at the base of the series to limestones and marine clays at the top. Generally they may be divided into five groups of beds, and, except the basal conglomerate stage, all are fossiliferous. The highest stage, consisting of clays and sandy beds, contains a characteristic Awamoan fauna. The limestone lying below these beds is mainly composed of Polyzoa, but also contains many molluscs (mostly pectens) and brachiopods, among which *Pachymagas parki* (Hutton) is common. In many places the limestone is glauconitic; on the fossil evidence it should be placed in the Ototaran stage.

The subdivision of the beds lying below the limestone is quite arbitrary. No attempt was made to make collections of fossils anywhere. Fossiliferous horizons are numerous, and some of them so stored with fossils that the making of an exhaustive collection would be the work of two years. In a few places examples of some of the larger molluscs were obtained for purposes of identification, and in other places a note was made of the fossils seen in place. A rich harvest awaits the collector at Clifden, Blue Cliff, and Mussel Beach. In this southern latitude there will probably be found many genera and species not recorded from Oamaru and farther north. No fauna with as old a facies as the Bortonian was seen anywhere in Southland.

The most complete section of the series is that exposed between the Hump and Helmet Hill, to the south of Lake Hauroto. There we have a continuous succession from the basal conglomerate to the base of the Hutchinsonian, showing a thickness of 2,000 ft.; the thickness of the Awamoan beds overlying the limestone in the Lillburn Valley to the north-east is about 400 ft.: thus the total thickness of the whole series in the south end of the Waiau basin is not less than 2,400 ft.

In the Blackmount area, twenty-five miles farther north, there is a tremendous development of the conglomerates, gritstones, and sandstones, the total thickness of which cannot be less than 4,000 ft.

PLATE VII.

VIEW LOOKING ACROSS LAKE MANAPOURI, WITH TERTIARY CONGLOMERATES IN FOREGROUND ON RIGHT.

At Blackmount and Sunnyside a great thickness of blue clays and limestones overlies the gritstones and conglomerates that compose Blackmount Ridge. Blue clays of unknown but considerable thickness appear to underlie the Blackmount Ridge beds. They are well seen in the Waiau–Borland section, where they apparently dip below the Blackmount Ridge beds. A powerful fault passes along the Waiau Valley, trending north and south, and possibly future investigation will show that these clays owe their present position to faulting.

Mussel Beach Section.

The lowest beds of the Middle Tertiary series are exposed on the coast at Mussel Beach, where, at the limestone caves half a mile north of the breakwater, they are seen in actual contact with the underlying hornblende-diorite which forms the base rock.

The Tertiary beds do not rest on an even wave-cut platform, but on an uneven surface diversified with low rocky pinnacles and ridges. We have evidence that here, at least, geographical change in the Early Miocene was so rapid that a broken rock-bound strand became suddenly submerged.

The lowest bed of the Tertiary formation is a sandy conglomerate, which passes upward into a brown sandstone. On this sandstone there rests a band of thin-bedded limestone 18 ft. in thickness, and over the limestone there is a bed of coarse, calcareous, shelly gritstone ranging from 24 ft. to 30 ft. in thickness. The gritstone is mainly composed of small angular and semi-angular fragments of granite, gneiss, diorite, quartz, and hornblende crystals. The ancient sea-floor was so uneven that in places the limestone rests directly on the diorite bed-rock.

North of the sandy bay near the breakwater the gritstone forms a wide platform just below high-water mark. Altogether for a distance of two hundred yards the outer edge of the platform is a straight wall that runs parallel with the strike, and slopes steeply towards the sea like an artificial sea-wall. The batter is steeper than the dip of the beds.

Immediately north of the breakwater the gritstone strikes north and south (magnetic), and dips east at an angle of 20°. Generally the angle of dip ranges from 10° to 15°, and there are abrupt local variations of strike and angle of dip. For a short distance near the caves the angle of dip is 75°, but this is abnormal, and has apparently arisen from the collapse of a block of gritstone owing to the solution and removal of the underlying limestone.

The fossils in the gritstone include cetacean bones, the teeth of a shark, crab-remains, corals (mostly *Flabellum*), Polyzoa, a large *Balanus* (often 2 in. in diameter), and numerous molluscs, among which were recognized *Cucullæa alta, Cardium spatiosum, Pecten huttoni, Venericardia difficilis, Glycymeris laticostata, G. globosa, Lima colorata, Limopsis, Arca, Panopæa, Mactra, Venus, Mytilus, Ostrea, Anomia, Scalaria lyrata, Teredo heaphyi, Trochus* or *Imperator*, and *Dentalium*. This fauna bears a curious resemblance to that of the sandy beds overlying the coal-measures at Wharekuri, in the Oamaru district.

Two miles north of the breakwater, at the south end of Anchor Bay, the gritstone is overlain by fossiliferous sandy beds and clays with limestone bands. At the south end of Anchor Bay the strike is N. 72° W., and the dip N.E. at angles ranging between 15° and 20°. Near the middle of the bay the beds are faulted, and tilted at high angles; in places they are vertical. Farther north they are warped or bent along the strike, which in a distance of sixty-five yards changes from N.N.W. to S.W., the angle of dip being about 15°. In this short distance the bending along the strike exceeds 90°, and probably arises from faulting accompanied by crush.

Clifden Sections.

Fine sections of the Middle Tertiary strata are exposed in the high cliffs bordering the west bank of the Waiau River, to the north of the bridge at Clifden, and in the high escarpments on the east side of the river a quarter of a mile below the bridge. The beds range from Waiarekan to Awamoan. At the bridge the limestone crosses the river obliquely, and here its strike is N.E.-S.W. (mag.), and the dip N.W. at an angle of 18°.

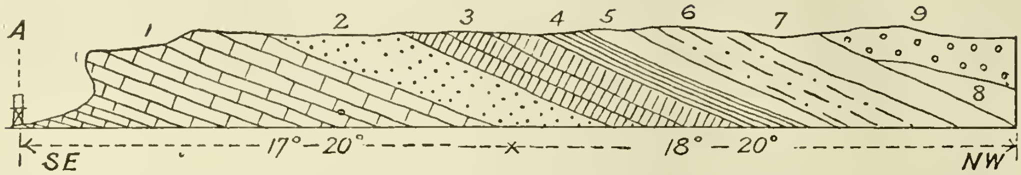


FIG. 1.—SECTION ALONG RIGHT BANK OF WAIAU RIVER, FROM CLIFDEN BRIDGE NORTHWARDS.

Horizontal scale, 400 ft. = 1 in.; vertical scale, 150 ft. = 1 in. A. Bridge across Waiau River at Clifden.

	Ft.
(1) Compact yellowish-grey polyzoan limestone, sandy in lower part	145
(2) Rusty-brown calcareous sandstone, glauconitic	45
(3) Sandy clays; fossils abundant	30
(4) Thin-bedded sands and clays; fossils few	15
(5) Blue clay with Foraminifera	20
(6) Sandy clays, richly fossiliferous	} 175
(7) Marly shelly sands, slightly glauconitic, fossiliferous	}
(8) Sandy clays, fossiliferous	230
(9) Terrace gravels.	

These beds may be grouped as under:—

(1) Limestone	} Ototaran.
(2) Calcareous sandstone	}
(3) Sandy clays	} Hutchinsonian.
(4) Thin-bedded sands and clays	}
(5) Blue clays	}
(6) Sandy clays	}
(7) Marly shelly sands	} Awamoan
(8) Sandy clays	}

Bed (6) contains many fine examples of *Ostrea wuellerstorfi*, a large *Pinna*, *Perna*, *Pachymagas parki*, and pieces of carbonized wood.

The river-cliff runs a little obliquely across the strike of the beds. The whole thickness of the limestone is not exposed in this section. In the high escarpment below the bridge the thickness is about 160 ft.

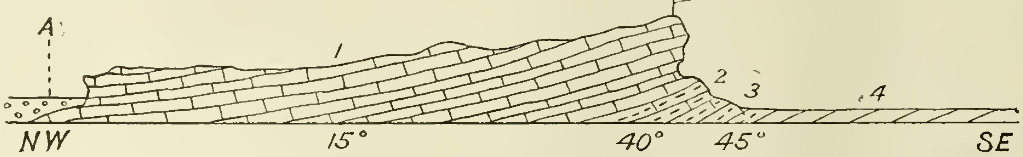


FIG. 2.—SECTION FROM CAVES ROAD, HALF A MILE FROM CLIFDEN BRIDGE SOUTH-EAST TO WAIAU RIVER.

A. Road to Caves.

(1) Limestone. (2) Impure gritty limestone with *Pachymagas parki*. (3) Grey calcareous sandy beds. (4) Sandstones and clays underlain by shaly clays and sandy beds with calcareous concretions and plant-remains.

To the south-east, beds (4) change their dip to the north-west not far from the mouth of the Orawia River, which flows into the Waiau River between Clifden and Tuatapere.

BLACKMOUNT SECTION.

Blackmount Hill is a prominent ridge that presents a precipitous dip-slope towards Ligar Creek and a moderate slope to the Waiau River. It is composed of brown gritty sandstone and conglomerates, which dip about south-east at high angles. These beds are followed by a great thickness of blue crumbling clays, in which Ligar Creek has cut its course near Blackmount

PLATE VIII.

Franklin Mountains on West Side of Lake Te Anau. The View shows Long Dip-slopes of Tilted Tertiary Strata.

 [*To face p. 52.*

homestead. The clays contain a few bands of harder clay rock, the strike of which is N.–S. (mag.), and the dip east at an angle of 45°.

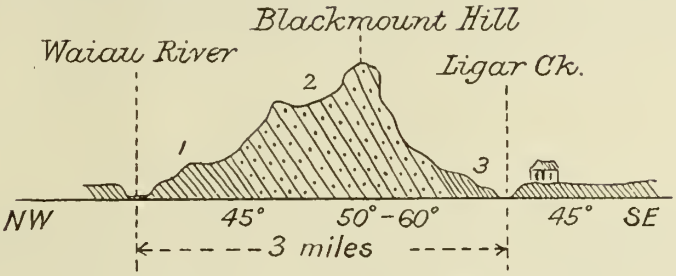


Fig. 3.—Section from Waiau River to Ligar Creek, One Mile below Blackmount Homestead.

(1) Blue clays. (2) Gritty sandstones and conglomerates. (3) Blue clays.

At the upper end of the gorge near Digger's Hill there is a wide platform of rock, on the right side of the Waiau River, composed of alternations of well-bedded clays and sandstones, which strike at first N. 10° E. (mag.), and dip easterly at an angle of 45°. A few hundred yards farther down the river-bed the strike bends more to the east; and at the big bend, where the clays and sandstones are interbedded with numerous bands of impure gritty limestone, the strike is N.E.–S.W. (true), and the dip south-east at angles ranging from 15° to 40°. Still farther down the river the calcareous beds are succeeded by the Awamoan clays and sandy beds.

The Middle Tertiary strata in the Sunnyside–Blackmount area are so faulted and warped that it is difficult to arrive at a trustworthy estimate of their thickness. It is certain, however, that the total thickness runs into many thousand feet.

Structure.

Along the walls of the Waiau Valley the Oamaruian strata are crushed and broken by the faults which bound the valley, and present no definite structure; but in the lower end of the valley, at some distance from the valley-walls, they are arranged as a flat syncline the axis of which runs N.E.–S.W., and lies between the mouth of the Orawia and Clifden.

In the Clifden basin, which includes the lower Lillburn and lower Wairaki valleys, the strata form a saucer-shaped syncline.

At the south end of Lake Manapouri the brown sandstones, gritstones, and conglomerates dip gently to the north-west and south-east. Near the head of Lake Te Anau, as seen in the small islands, they dip gently to the north, north-east, or north-west; but a short distance from the shores they are sharply tilted along the plane of powerful faults, and on both sides of the lake rise to a height of 5,000 ft. or more on the slopes of the ranges. On the west side of the lake the Tertiary strata form conspicuous sharp-crested ridges with long steep dip-slopes, and on the east they crown some of the higher peaks of the Earl Mountains.

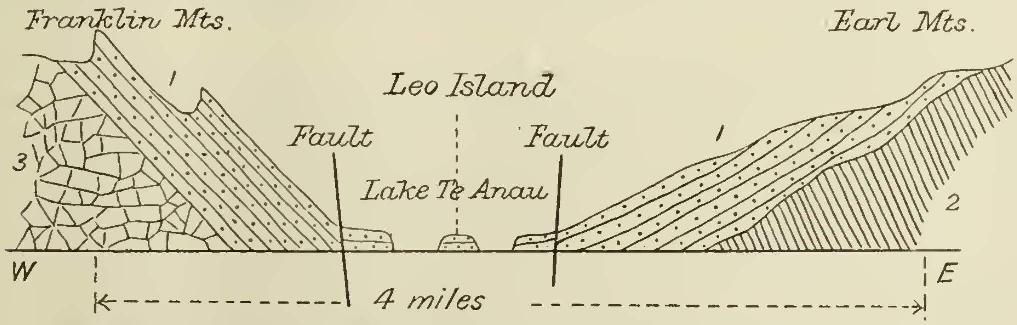


Fig 4.—Section from Franklin Mountains across Lake Te Anau to the Earl Mountains.

(1) Middle Tertiary sandstones, &c. (2) Permo-Carboniferous argillites and greywackes. (3) Diorites of Clinton River intrusive series.

Economic Minerals.

The Tertiary formation contains valuable deposits of clay and limestone, and thick seams of brown coal. Economically it is the most important rock-series in Southland. A description of some of the more important of these is given in Chapter VIII.

PLEISTOCENE DEPOSITS.

Orepuki Clays, Silts, and Sandy Beds.

From near Monkey Island, near Orepuki, to Rowallan Burn the shore of Te Waewae Bay is fringed with high cliffs composed of clays, silts, and sandy beds, intercalated with seams of woody lignite ranging from a few inches to 5 ft. in thickness. In places they contain logs of drift timber partially carbonized. These beds are present at Round Hill, and generally they do not extend inland more than two or three miles. They are a marginal deposit laid down in the old delta of the Waiau River. No marine organisms are known to occur in them. In the sea-cliffs at Orepuki they show a thickness of 100 ft., but their total thickness must be greater, as the bottom beds are not exposed. They lie unconformably on the Oamaruian Tertiaries, or on the diorites and gabbros that intrude the Longwood argillites and greywackes. The tree-trunks embedded in the sandy beds are only partially carbonized, and frequently the bark is still tough and pliable.

The lowest sandy bed, where it rests on the bed-rock, as a rule contains scattered pebbles; and a few small pebbles sometimes occur in some of the higher beds, but this is exceptional. Usually the series consists of well-bedded clays, silts, and fine sands, often showing current-bedding, only the lowest stratum being gravelly or pebbly.

These Pleistocene beds contain gold; and at one time a large number of alluvial claims were worked at Round Hill, on the sea-beaches between Orepuki and the mouth of the Waiau River, and along the courses of the small streams flowing into Te Waewae Bay, where a certain amount of secondary concentration had taken place. The gold occurs in fine flaky particles, and is everywhere associated with grains of platinum.

The minerals found with the gold and platinum in the alluvial concentrates are magnetite (which is abundant), specular iron, red garnets, zircons, and spinels.

The platinum was most abundant at Round Hill and at the mouth of the Waiau River. Generally, about 1 oz. of platinum was obtained for every 100 oz. of gold. The association of the gold and platinum invests these deposits with a peculiar interest. The source of the gold is doubtless to be found in the gold-bearing veins which occur in the argillites and greywackes at the sources of the Orawia River, which rises on the west side of the Longwood Range and falls into the Waiau River two miles above Tuatapere. The platinum is probably derived from the gabbro intrusions in the Longwood Range drained by the Orepuki, Waimeamea, and Waihoaka streams. The occurrence of platinum in gabbro and other basic rocks has been definitely determined in the Ural Mountains. Mr. L. S. Hundeshagen* has recorded the occurrence of platinum in Sumatra, in wollastonite which is associated with schists, granite, and augite-diorite or gabbro.

The Pleistocene lignitic silts and sandy beds occur at Round Hill at a height of 230 ft. above the sea. As the beds were evidently laid down at sea-level, their present elevated position is an evidence of uplift in quite recent times. At one time, not earlier than the Pleistocene, ridges of the Tertiary limestones and sandstones formed high barriers across the Waiau Valley at Clifden, Digger's Hill, near Sunnyside, and at the end of Blackmount Hill. The waters of the Waiau River were ponded above these barriers, forming lake-basins that became partially filled with river-drift. When the last uplift of the land took place the notches in the barriers were cut down deep enough to permit the Waiau River to drain the basins, and terrace the gravels lying on the floor of the basins. By the blocking of the

* *Trans. Inst. Min. and Met. London*, vol. 13, 1904.

Clifden, Digger's, and Blackmount gorges with artificial barrages the ancient lakes could be recreated in the Waiau Valley, though of smaller dimensions than the Pleistocene lakes, as rain and glacier-ice have greatly reduced the crests of the ridges forming the walls of the gorges. These ancient lake-basins owed their existence to the tilting of the Tertiary strata in a direction running diagonally to the general north-and-south course of the Waiau Valley. The tilting accompanied the faulting which originated the Waiau rift-valley.

Mararoa Clays and Silts.

Along the north bank of the Mararoa River, to the east of the Key bridge, the river-cliffs are composed of blue clays and silts interbedded with a stratum of loosely compacted conglomerate ranging from 4 ft. to 12 ft. in thickness. The material composing this conglomerate is mainly greywacke and quartzose pebbles, grit, and sand derived from the Livingstone and Takitimu mountains. Embedded in the conglomerate there occur the trunks and branches of trees now partially carbonized, and intercalated in the clays there are seams of impure lignite. The clays and associated beds dip towards the north-west at an angle of about 15°. Their visible thickness as exposed on the west bank of the Mararoa is about 300 ft. They are overlain unconformably by a considerable thickness of fluvio-glacial drift, mainly composed of granite, gneiss, diorite, and quartz. To the south, in Princhester Creek, the Mararoa clay and silt beds rest unconformably on the Oamaruian coal-measures.

These beds are of fresh-water origin. They were evidently deposited on the floor of the Late Pliocene or Early Pleistocene lake that occupied the Mararoa basin. The ancient Mararoa Lake included Lake Te Anau and Lake Manapouri, and extended down the Waiau Valley to Redcliff Creek. They were tilted by movement along the great Waiau fault, probably before the period of maximum refrigeration in the Middle Pleistocene.

High-level, Glacial, and Fluvio-glacial Drifts and Moraines.

High-level gravels occur as terraces or scattered deposits up to a height of 800 ft. above the bed of the Waiau River from Clifden north to Te Anau. In the Clifden basin they are purely fluviatile ; in the Sunnyside basin, partly fluviatile and partly fluvio-glacial ; and in the Manapouri - Te Anau basin, which has already been referred to as the Mararoa basin, mainly fluvio-glacial. At the south end of Lake Manapouri, at the end of Lake Monowai, in the area separating Lake Hauroto and the Lillburn River, and at the lower end of Lake Ada there are great accumulations of glacial material of the fluvio-morainic type—that is, they are composed of tumbled blocks of rock mingled with a large proportion of fluviatile drift. The greatest development of the fluvio-glacial drifts is in the ancient Mararoa basin, where, as in the Ramparts, they form ridges that rise to an elevation of 1,380 ft. above the sea, or 100 ft. above the present level of Lake Te Anau.

Scattered throughout the drifts in the Mararoa basin there are numerous ice-borne erratics of gneiss, granite, or diorite, derived from the mountains on the west side of Lake Manapouri and Lake Te Anau.

Among other evidences of intense Pleistocene glaciation are the smooth, rounded, and hummocky contours presented by many of the ridges and spurs of the main divide ; the deep, cañon-like, flat-bottomed, U-shaped valleys, varied only by sudden steps, and ending abruptly in the heart of the main chain as a *cul-de-sac* or cirque hemmed by sheer walls that are in some cases over 2,000 ft. high ; hanging-valleys, of which those at the Stirling and Bowen falls are fine examples ; and fine ice-striated surfaces.

On the south-west shore of Circle Cove, at the south end of Lake Manapouri, there occurs the largest and finest stretch of ice-grooved rock-surface in New Zealand. It was discovered by Mr. J. M. Fowler, of Invercargill, and Mr. Guy Murrell, of Manapouri, in May, 1919. The striated rock is an intensely hard, granitic-looking, gritty, quartzose Tertiary sandstone. The striated surface runs parallel with the shore, and is about a hundred and fifty yards long and twenty yards wide. The full extent of the ice-worn rock is not exposed to view, as the striated surface dips below water-level on one side and is covered with a boulder drift on the landward side and at the ends. The strike of the ice-grooves is about N. 80° W. (mag.). A detailed description of the discovery will be found in the *Transactions of the New Zealand Institute*.*

RECENT ACCUMULATIONS.

These include the sandhills and storm-beaches on the coast between the mouth of the Waiau River and Blue Cliff, the alluvial flats of the lower Clinton and Arthur valleys, and the deltaic accumulations at the mouth of the Arthur, Cleddau, and other rivers flowing into the Sounds and arms of the lakes.

A noticeable feature of the glaciated country lying to the west of the Waiau Valley is the absence of residual clays. The deposits of residual clays are unimportant till the low-lying areas in the neighbourhood of Clifden and Tuatapere are reached.

At the upper end of Lake Ada there is a submerged forest. The submergence is not due to land-movement, but has arisen from the consolidation and consequent shrinking of the fine deltaic sediments on which the forest grew. There is evidence of submergence from the same cause in the deltaic areas along the shores of Lake Hauroto.

* J. M. Fowler: On an Ice-striated Rock-surface on the Shore of Circle Cove, Lake Manapouri, *Trans. N.Z. Inst.*, vol. 53, 175, 1921.

CHAPTER VIII.

COAL RESOURCES AND OIL PROSPECTS.

WAIRIO COALFIELD.

Coal-measures and Coal-seams.

The Middle Tertiary coal-measures underlie the Oreti Plain. At Nightcaps they abut against the Palæozoic base rock, and thence extend westward, through the narrow gap separating the Longwood Range and Takitimu Mountains, to the Waiau Valley.

The Nightcaps, Wairio, Quested's, Ohai, and Mount Linton fields are mining centres in the same series of coal-measures. Generally the coal-measures are characterized by a great thickness of clayey beds.

The succession of the measures in the Wairio coal-area is—

(1) Bluish-grey clays.
(2) Rosin coal-seam, 4 ft. to 13 ft. thick, where it is usually split with seam of shaly clay.
(3) Shaly clays, sandy clays, and sands, with thin bands of ironstone and shaly coal.
(4) Soft white sandstone, 9 ft. to 30 ft.
(5) "Big seam" of coal, 9 ft. to 20 ft.
(6) Fireclay, 3 ft.
(7) Seam of impure coal (lignite), 6 in. to 24 in.
(8) Soft grey sandstone, 4 ft. to 5 ft.
(9) Seam of coal, 2 ft. to 5 ft.
(10) Clays with bands of limonitic sandstone, 40 ft. to 300 ft.

As at Nightcaps to the east and Ohai to the west, there are two workable seams in the Moretown–Wairio area—a lower seam of good brown coal locally called the "big seam," and an upper seam called the "rosin seam." The lower seam, in the Wairio area, ranges from 9 ft. to 20 ft. in thickness, and the rosin seam from 4 ft. to 13 ft. The lower seam is a hard brown coal of good quality; and the rosin seam is a bright friable coal that everywhere contains a large amount of ambrite, or fossil resin, disseminated throughout the whole thickness as large and small grains and fragments, ranging from the size of a pea to that of a walnut.

Structure of Coal-measures.

The coal-measures at Wairio dip towards the south-west at low angles, and rise towards Quested's to the north-east, where they abut against the Palæozoic base rock along the plane of a fault that strikes N.W.–S.E. and approximately forms the boundary of the coal-measures from Quested's to the Ohai River.

Between Nightcaps and Ohai denudation has removed the greater part of the coal-measures to the north and north-east of Fish Creek, and the patches that still remain on the ridges are covered with only a thin layer of fireclay. In some places the coal-measures overlying the upper seam of coal have been completely removed. In this case the coal is overlain directly by the partially consolidated fluviatile high-level gravels that form the White Range. The arrangement of the Moretown coal-measures and coal-seams, and their relationship to Quested's coal area, are shown in fig. 5.

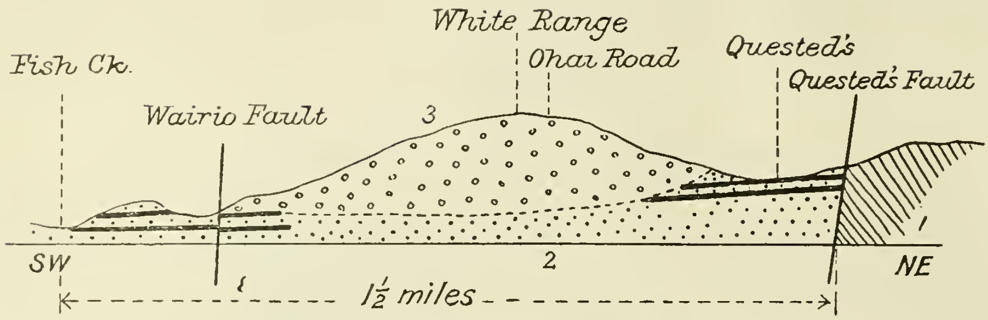


Fig. 5.—Section from Moretown across White Range to Quested's.

(1) Palæozoic argillites and greywackes. (2) Coal-measures with two seams of coal. (3) Pleistocene gravels.

The seams are displaced by a system of faults running parallel with the strike, and by a second system of dip-faults.

The amount of coal remaining unworked to the rise in the Moretown area of the Wairio coalfield is small, and probably does not exceed 100,000 tons altogether. The coal-measures and seams dip below the downs to the south-west of Fish Creek. The amount of coal existing to the dip can only be ascertained by boring. Whatever coal does occur in this direction will be below water-level.

The only large block of coal now remaining on this field to the rise exists at Mossbank No. 2. A good seam of coal has been uncovered on this property, but the amount of development carried out is insufficient to enable a trustworthy estimate to be made of the quantity of coal that may be available. Nevertheless, it is probable that several hundreds of thousands of tons of coal may be profitably mined.

Like all brown coals, the Wairio coals vary considerably in composition, both throughout the thickness of the seams and in lateral extension. The analyses of what may be regarded as approximately representative samples are given below:—

	Big Seam.	Rosin Seam.
Fixed carbon	40·90	40·80
Volatile hydrocarbons	30·60	37·40
Water	22·40	18·80
Ash	6·10	3·00
	100·00	100·00
Sulphur (per cent.)	0·95	0·23

QUESTED'S COAL AREA.

This coal-bearing area lies in the basin to the north-east of White Range. The relationship of the coal-measures and their two seams of coal—the "big seam" and the "rosin seam"—to the Wairio coal-measures and seams is shown in fig. 5. To the north-east the Tertiary rocks are bounded by a fault; and to the south-west they dip below the Pleistocene gravels that form the White Range. To what distance the seams continue below the gravels is unknown. To the north-east Quested's fault runs obliquely across the strike of the coal-measures, and in consequence the different members of that series abut successively against the base rock. At Quested's opencast the "rosin seam" lies almost against the bed-rock; to the south-east—that is, towards Nightcaps—the underlying members in succession come against the base rock.

To the south-west of the place where the "rosin seam" crops out, near the base rock, the "big seam" should be found underfoot—that is, if it escaped destruction by the ancient river which deposited the White Range gravels.

At Quested's the "rosin seam" is about 12 ft. in thickness at the outcrop. An analysis of a sample from this seam by the Dominion Analyst gave the following results :—

Fixed carbon	36·40
Volatile hydrocarbons	43·90
Water	16·60
Ash	3·10
	100·00
Sulphur (per cent.)	0·29

OHAI COALFIELD.

At the Wairaki Mine, on the south side of the Ohai River, the coal-seams dip to the south-west at an angle of about 8°, and on the north side of the river the Mount Linton seams dip towards the west at an angle of 5°. In a distance of a few hundred yards the strike changes from north-west to north-east. This peculiar structure has been brought about by the intersection of two systems of faults. At Clapp's coal-mine, situated about half a mile to the north-east of Mount Linton, the dip of the coal is north-west at an angle of 45°. At this place the coal-measures abut against the Palæozoic bed-rock, as shown in fig. 6.

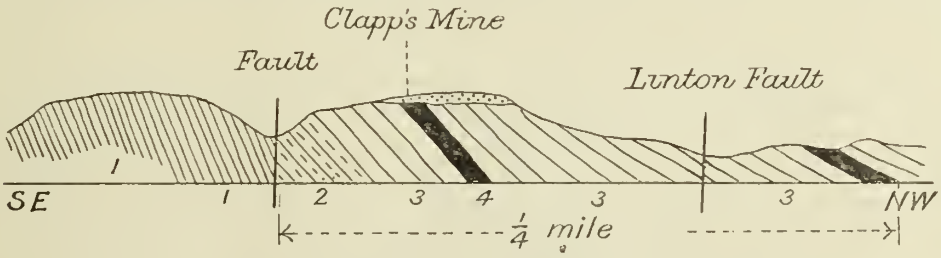


Fig. 6.—Section at Clapp's opencast Coal-mine.

(1) Palæozoic bed-rock. (2) Gritty sandstones. (3) Blue clay. (4) Clapp's coal-seam.

At Mossbank No. 1 there is a seam of good coal 40 ft. thick. It is exposed in the bottom of the valley, and is being worked as an open quarry close to the Ohai Stream. The over-burden consists of Recent gravels and clays. The dip of the seam, as has been shown by Mr. Ongley,* is about south-west at an angle of about 11°. In consequence of faulting, Pleistocene denudation, and small amount of development work, it is impossible to estimate the amount of coal available in this block. To the rise, or north-east, the seam is not more than four hundred or five hundred yards from the base rock, and even in that distance there is some evidence of faulting. Towards the south-west the dip, if continued, would carry the Mossbank seam below the Wairaki seam, which dips in the same direction and crops out at the foot of the terrace on the south side of the river-flat.

The Wairaki seam is about 10 ft. in thickness, and is exposed at two places in the face of the terrace. This terrace looks like a fault-scarp, and future development may prove that the Mossbank "big seam" is the Wairaki seam. The latter is traversed by four parallel dip-faults that upstep the seam to the north-west a height of 120 ft. in a distance of half a mile.

At the Mount Linton Mine, half a mile farther down the valley, the present workings are in the lower 23 ft. seam, which dips to the westward at an angle of 5°.

The upper 10 ft. seam is separated from the lower by a thin band of "fireclay." From the Linton fault to the east side of the hill designated Trig. U, a distance of half a mile,

* M. Ongley : *Ann. Rep. Geol. Surv. Branch*, C.–2b, p. 8, 1917

towards the rise, this seam and the overlying "rosin seam" have been completely destroyed by fire. The removal of the coal by burning has allowed the ground overlying the seam to cave in or collapse, and the heat of the burning coal has baked the overlying laminated clays into rich red-coloured tiles. In places the clays have been burnt into masses of excessively hard clinker. The burnt clays, the wide expanse of narrow ridges and caved-in ground, diversified by pinnacles of clinkered clay, form a weird landscape unlike any other in New Zealand, and strikingly reminiscent of some parts of the Rotorua volcanic regions. The area of burnt ground, as determined by the surface caving, is about 160 acres. If the average thickness of the "rosin seam" be taken at 10 ft., the estimated quantity of valuable coal destroyed by fire is about 4,000,000 tons.

The thin bed of fireclay separating the upper seam prevented the fire spreading to the lower seam at the present Mount Linton workings, but there is a possibility that towards Trig. U the fire may have reached the lower seam. Even if the fire did not actually reach the "big seam," the management should be prepared to find that the upper part of the seam has been cindered by the heat over a considerable area lying to the west of the Linton fault. Besides this, the great depth of the caving has destroyed the continuity of the natural roof-cover, and this will increase the cost of mining. To the dip side of the opencast the seams are, so far as known, practically unaffected by the fire, and remain intact.

The date of the fire is unknown. The Maoris of Southland have no traditions relating to it; probably they never knew of it. The pinnacles of clinkered clay stand 6 ft. or 8 ft. above the general surface, and this circumstance would tend to show that considerable denudation has taken place since the burning of the seam.

The origin of the fire is also unknown. It may possibly have been started by a burning forest fired by lightning, or by spontaneous combustion traceable to the crush and heating arising from faulting. But these are only surmises.

About four hundred yards east of the Mount Linton opencast, at the same level and to the north of the tram-line, there is an outcrop of a large seam of brown coal broken by a layer of fireclay. This seam has not been fully disclosed by prospecting-work, but, so far as can be seen, it appears to be altogether about 20 ft. thick. It dips towards the north-west at a low angle —that is, towards the Mount Linton opencast—and for that reason Mr. T. Smith, of Moretown, the former owner of this property, has expressed the view that it is a second "big seam" underlying the Mount Linton seam. It should, however, be noted that it occupies the same relative position to the burnt "rosin seam" as does the Mount Linton seam; and for that reason the author favours the view that it is a down-faulted part of the Mount Linton seam.

At the Mount Linton opencast workings a strike-fault follows the gully or depression drained by the small stream which flows across the outcrop of the coal. According to Mr. Ongley the "rosin seam" crops out on the west side of the depression.

The arrangement of the coal-measures and contained seams of coal is shown in fig. 7.

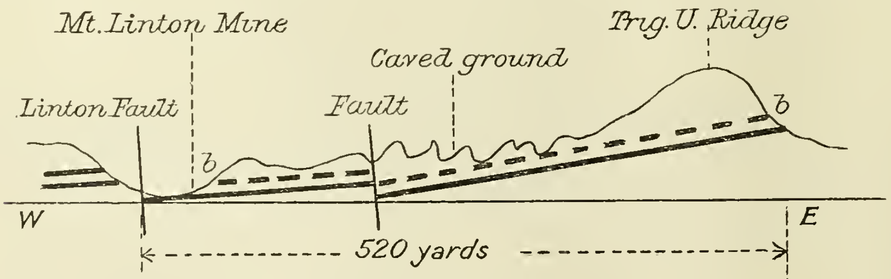


Fig. 7.—Section from Mount Linton Opencast to Trig. U Ridge—Oblique to Strike.

b. Burnt outcrops of "rosin seam."

At the Wairaki Mine the "big seam" possesses the south-west dip of the Mossbank No. 2 and Wairio seams. How far the seam will live to the dip and extend along the strike is unknown at present. If no large faults are encountered it is probable that a large area of coal may be developed towards the dip, lying below water-level.

At the old Mount Linton pit, situated on the north bank of the Ohai River, about three and a half miles down the valley from the present Mount Linton Mine, the "big seam" shows a thickness of about 20 ft. of coal. The pit was subject to the influx of water from the Ohai River, and ten years ago work at this place was abandoned.

In the bed of a small stream about a mile west of Mount Linton Mine black shaly clays contain casts of a fresh-water mussel in abundance (*Diplodon inflatus* (Hutt.)). These clays appear to overlie the "rosin seam."

Borehole Records.

In 1910 Mr. A. W. Rodger prospected the coal-measures lying below the Ohai Flat by a chain of twenty-four boreholes, spaced from two hundred to three hundred yards apart, No. 1 bore being situated opposite the Wairaki Mine and No. 24 near Birchwood Dairy Factory. The borehole records prove (*a*) that the coal-measures maintain the Mount Linton westerly dip for a distance of three miles, (*b*) that two workable seams of coal exist in the valley for a distance of a mile and a half from Mount Linton, and (*c*) that beyond this the coal thins out rapidly towards the dip. The borehole results are placed on record for future reference:—

Bore No. 1.	Feet.
Recent gravels..	10
White clay	5
Blue pipeclay ..	3
Seam of coal ..	12
Sandstones and clays	20
Total depth ..	50

Bore No. 2.	
Recent gravel ..	7
Seam of coal ..	7
Sandstone	5
Fireclay	12
Sandstone	8
Fireclay	1
Seam of coal ..	6
Sandstone	13
Hard sandstone and conglomerate	21
Total depth ..	80

Bore No. 3.	
Recent gravel ..	16
Sandstone	6
Fireclay	10
Seam of coal ..	5
Fireclay	2
Seam of coal ..	14
Black shaly clay (bat) ..	33
Total depth ..	86

Bore No. 4.	Feet.
Recent gravel ..	16
Seam of coal ..	4
Fireclay	3
Seam of coal ..	4
Black shaly clay (bat) ..	4
Clay and sandstone	30
Seam of coal ..	5
Sandstone	17
Conglomerate ..	23
Sandstone	35
Conglomerate ..	13
Total depth ..	154

Bore No. 5.	
Recent gravel ..	9
Seam of coal ..	4
Fireclay	3
Sandstone	25
Fireclay	7
Sandstone	10
Fireclay	8
Seam of coal ..	4
Fireclay	5
Seam of coal ..	5
Fireclay	6
Conglomerate ..	4
Total depth ..	90

Bore No. 6.

	Feet.
Recent gravel	9
Sandstone	11
Seam of coal	5
Black shaly clay	1
Fireclay	14
Sandstone	8
Fireclay	11
Seam of coal	4
Sandstone	1
Fireclay	4
Seam of coal	1
Fireclay	6
Sandstone	11
Fireclay	2
Blue clay	24
Total depth	112

Bore No. 7.

Recent gravel	14
Sandstone	30
Fireclay	1
Black shaly clay	2
Seam of coal	4
Sandstone	4
Seam of coal	14
Fireclay	8
Total depth	77

Bore No. 8.

Recent gravel	17
Sandstone	15
Fireclay	5
Seam of coal	4
Sandstone	6
Fireclay	3
Seam of coal	12
Fireclay	2
Total depth	64

Bore No. 9.

Recent gravel	14
Fireclay	18
Seam of coal	4
Sandstone	14
Fireclay	3
Seam of coal	12
Fireclay	4
Total depth	69

Bore No. 10.

Recent gravel	8
Fireclay	15
Sandstone	10
Fireclay	19
Seam of coal	7
Fireclay	9
Blue clay	12
Total depth	80

Bore No. 11.

	Feet.
Recent gravel	6
Sandstone	15
Fireclay	1
Seam of coal	1
Sandstone	17
Blue clay	40
Total depth	80

Bore No. 12.

Recent gravel	5
Sandstone	21
Hard sandstone	4
Fireclay	3
Sandstone	12
Fireclay	5
Seam of coal	6
Blue clay	9
Seam of coal	8
Sandstone	7
Total depth	80

Bore No. 13.

Recent gravel	16
Fireclay	9
Sandstone	4
Fireclay	20
Sandstone	36
Fireclay	5
Blue clay	10
Seam of coal	4
Sandstone	4
Blue clay	22
Seam of coal	9
Blue clay	2
Total depth	141

Bore No. 14.

Recent gravel	6
Sandstone	8
Fireclay	9
Black shaly clay	1
Seam of coal	3
Black shaly clay	14
Seam of coal	2
Black shaly clay	3
Seam of coal	1
Black shaly clay	31
Seam of coal	10
Dark-grey clay	4
Total depth	92

Bore No. 15.

Recent gravel	15
Sandstone	30
Fireclay	25
Sandstone	15
Black shaly clay	6
Sandstone	9
Total depth	100

Bore No. 16.

	Feet.
Recent gravel	9
Fireclay	85
Seam of coal	4
White clay	2
Total depth	100

Bore No. 17.

	Feet.
Recent gravel	10
Fireclay	30
Seam of coal	4
Fireclay	10
Sandstone	26
Seam of coal	5
Fireclay	6
Conglomerate	9
Total depth	100

Bore No. 18.

	Feet.
Recent gravel	10
Claystone	125
Total depth	135

Bore No. 19.

	Feet.
Recent gravel	9
Claystone	91
Total depth	100

Bore No. 20.

	Feet.
Recent gravel	8
Fireclay	47
Seam of coal	3
Blue clay	45
Sandstone	10
Blue clay	5
Total depth	118

Bore No. 21.

	Feet.
Recent gravel	10
Fireclay	7
Seam of coal	2
Blue clay	23
Sandstone	30
Claystone	42
Total depth	114

Bore No. 22.

	Feet.
Recent clay and gravel	10
Claystone	37
Sandstone	4
Black shaly clay	1
Seam of coal	1
Claystone	18
Sandstone	39
Fireclay	14
Sandstone	20
Fireclay	4
Sandstone with gas	12
Quartz rock	2
Consolidated sand	5
Sandstone with gas	5
Claystone with fireclay	49
Seam of coal with gas	4
Fireclay, white	10
Claystone	7
Fireclay	15
Cemented sand	1
Fireclay	7
Dark fireclay	4
Seam of good coal	6
Fireclays with coaly matter	56
Quartz rock	1
Fireclay	18
Seam of coal	4
Blue clay	2
Total depth	356

Bore No. 23 (at Dairy Factory).

	Feet.
Recent gravel	4
Blue clays	181
Total depth	185

Bore No. 24.

	Feet.
Recent gravel	15
Blue clays	90
Total depth	105

Borehole No. 22, from which there was an emission of inflammable gas, is situated on the Ohai Flat at the junction of the Ohai Valley Road and the road connecting that road with the main Birchwood Road. Two samples of the gas were analysed by Mr. G. D. Macindoe with the following results:—

	No. 1.	No. 2.
Methane	60·00	58·89
Carbon monoxide	7·36	7·41
Carbon dioxide	2·05	2·25
Hydrogen	1·83	1·79
Nitrogen	22·57	23·66
Oxygen	6·19	6·00
	100·00	100·00

Analyses of Ohai Coals.

A, Mossbank No. 1, 40 ft. seam; B, Wairaki seam; C, Mount Linton "big seam"; D, Clapp's "big seam," 27 ft.

	A.	B.	C.	D.
Fixed carbon	46·90	44·10	41·80	45·60
Volatile hydrocarbons	32·60	36·70	40·03	36·10
Water	17·70	15·80	16·07	16·90
Ash	2·80	3·40	2·10	1·40
	100·00	100·00	100·00	100·00
Sulphur (per cent.)	0·83	0·20	0·27	0·46

A, by Otago School of Mines; B, C, D, by Dominion Analyst.

Amount of Available Coal.

Apart from the coal destroyed by fire, the total amount of coal contained in the different blocks in the Ohai basin, as estimated from the existing outcrops, coal-workings, and boreholes, probably exceeds 4,000,000 tons. Of this amount 60 per cent., or 2,400,000 tons, should be profitably mined when the field is linked up with the Nightcaps–Invercargill Railway.

OTHER POTENTIAL COAL AREAS.

Outcrops of coal have been found on the east side of the Waiau Valley at Loudon Hill, head of Taylor's Creek, near Redcliff Creek, near Whare Creek, at the source of Elm-tree Creek, at Princhester Creek, on the bank of Upukerora Creek, and on the shore of Lake Te Anau near Leo Island. In other places pieces of coal have been found in the bed of the stream draining the Hump, to the west of Blue Cliff; in the Iris Burn, which flows into Lake Manapouri; and in the streams draining the areas occupied by the coal-measures on the west side of Lake Te Anau.

At Princhester Creek and Upukerora the coal has been mined for many years by open faces for local requirements. Elsewhere no development work has been attempted, on account of the great distance from a market.

At Princhester Creek there are two seams of coal faulted against the red argillites of the Takitimu Palæozoic series. The lower seam is 4 ft. thick, and the upper, the "rosin seam," 6 ft. thick. These seams are separated by 2 ft. of hard shaly fireclay. The upper seam is overlain by a bed of blue clay. Both seams are crushed, and the blocks of available coal are very small.

The composition of the "rosin seam" is shown by the following analysis made in the Dominion Laboratory:—

Fixed carbon	37·00
Volatile hydrocarbons	44·10
Water	15·70
Ash	3·20
	100·00
Sulphur (per cent.)	0·24

The Upukerora fuel is a superior lignite. It occurs as a 10 ft. seam in clays that appear to belong to a higher horizon than the coal-measures at Princhester Creek.

Dr. Maclaurin, Dominion Analyst, reports that a sample of this coal submitted to him for analysis gave the following results :—

Fixed carbon	32·70
Volatile hydrocarbons	39·85
Water	23·80
Ash	3·65
	100·00
Sulphur (per cent.)	0·22

The coals cropping out on the east side of the Waiau Valley are generally crushed and faulted. Perhaps the most promising coal area is that situated at the head of Deep Creek, a tributary of Grassy Creek. Two seams crop out on the face of Flagstaff Hill, to the north-west of Loudon Hill. One of these is the "rosin seam" of Ohai. A sample from this seam was analysed at the Otago University with the following results :—

Fixed carbon	34·50
Volatile hydrocarbons	38·60
Water	18·60
Ash	8·30
	100·00
Sulphur (per cent.)	2·51

The second seam, though inferior in quality, probably represents the lower seam as seen at Ohai and Wairio. An outcrop sample had the following composition :—

Fixed carbon	32·60
Volatile hydrocarbons	35·10
Water	18·10
Ash	14·20
	100·00
Sulphur (per cent.)	1·43

The coal-outcrops in this area should be opened out to determine the probable extent of the seams.

USE OF PULVERIZED COAL.

The mining of all coals is attended with the production of a large proportion of small coal and coal-dust. Generally, the loss incurred in the mining of brown coals is higher than with high-grade coals. The high and increasing cost of coal has directed renewed attention to the utilizing of waste coal in the pulverized form.

For many years pulverized coal has been used in connection with the Portland-cement industry. The revolving cylindrical calciners utilize the heat to great advantage, as the long flame, so readily produced by the combustion of pulverized coal, is under better control than grate combustion. The utilization of pulverized coal has been taken up energetically in America, and many systems have been devised for the use of this form of fuel for industrial heating. It has been shown that low-grade fuels such as brown coal and lignite may be burned efficiently, regardless of the proportion of ash, sulphur, or other impurities. Pulverized coal possesses semi-fluid properties, and may be transferred through pipes to scattered industrial furnaces by (*a*) screw conveyers, (*b*) compressed air, or (*c*) in suspension in a current of air.

In practice the fuel is injected into the furnace in a finely divided state, and in its passage to the furnace is mixed with the proper volume of air, which may or may not have been previously heated. In the furnace the volatile gases are immediately driven off ; and for the combustion of these and the remaining particles of carbon the requisite oxygen is furnished by the accompanying current of air. The processes of disintegration and combustion are so rapid that a high temperature is maintained. The alternating high temperatures and cooling that are inseparable from grate firing are avoided.

To obtain the fuel in a finely divided state the coal is crushed, dried, and pulverized. It is crushed in a breaker, dried in a drier at a temperature not exceeding 200° C., and then conveyed to the grinder. At some point between the drier and grinding-mill there is placed a magnetic separator to withdraw any iron that may be present.

The cost of pulverizing decreases rapidly as the capacity of the plant increases. American engineers claim that a great economy of fuel-cost is obtained by the use of pulverized coal.

Besides its utilization in the manufacture of cement, pulverized coal may be employed in various metallurgical processes, for steam-raising in stationary boilers, and in locomotives. In the future the most promising field for the use of pulverized fuel will be found in the generation of electric energy at the coal-mine for distribution to industrial centres.

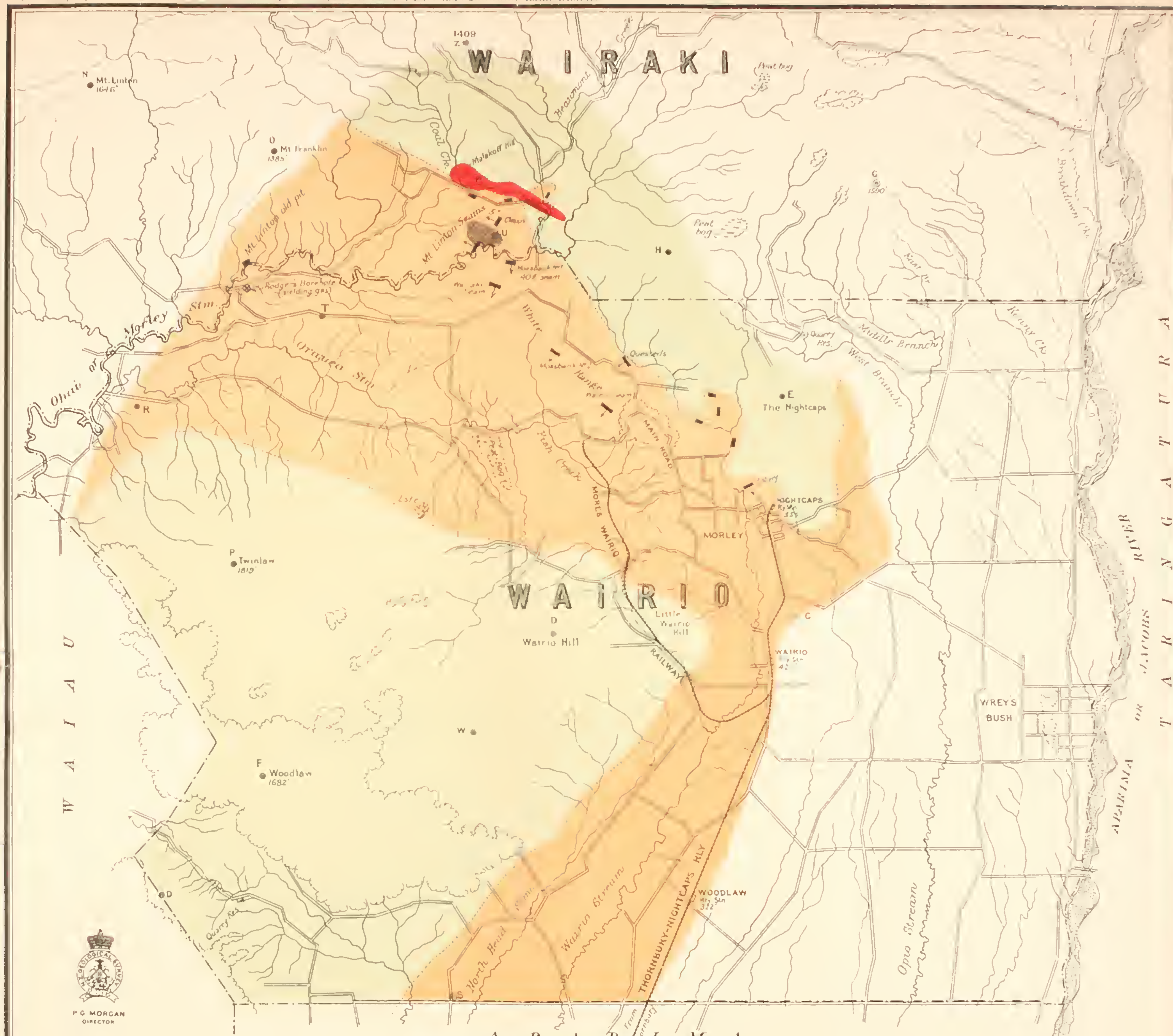
Unlike forests, coal-seams when exhausted cannot be renewed. To conserve our coal resources by the prevention of wasteful methods of mining, and to obtain the highest efficiency from the fuels used for industrial purposes, are concerns of national importance.

PROSPECTS OF AN OIL-DISCOVERY.

At Clifden the Tertiary strata dip north-west, and at the mouth of the Orawia River south-east. The axis of the anticline lies midway between Clifden and the mouth of the Orawia. The lower members of the series, comprising alternating beds of limestones, clays, and sandstone, are of great thickness, and contain the remains of marine organisms in abundance. If an oil-pool exists anywhere in western Southland it will be found in this area. The structure, character of strata, and relationship to the old shore-line are favourable for the occurrence of oil, and would justify boring on the Waiau Flat midway between Tuatapere and Clifden. There is always the possibility that, even if no oil is struck, a good seam of coal or oil-shale may be discovered.

A great thickness of Middle Tertiary strata underlies the Oreti plains, dipping gently seaward as a flat monoclinal. Here also there may exist pools of oil or accumulations of gas in profitable amount. The production of gasolene—a valuable motor spirit—from natural gas is a large and flourishing industry in the United States of America. One thousand cubic feet of so-called " wet " gas yields a pint or more of gasolene. In 1920 the total production amounted to 70,000,000 gallons.

To accompany Bulletin N° 23, Western Southland, Southland and Fiord Divisions, Southland Land District



GEOLOGICAL MAP OF

PARTS OF WAIRAKI AND WAIRIO SURVEY DISTRICTS

SHOWING SOLID GEOLOGY OF

NIGHTCAPS, WAIRIO AND OHAI AREAS

— Reference —

Roads	*shown thus*
Tracks	" "
Trigonometrical Stations	" "
Edges of Bush	" "
Swamp	" "
Water Races	" "
Railways	" "
Survey Dist boundary	" "

— Scale of Chains —

Kilometres

1 : 63360

Topography from Lands and Survey Dept. lithographs.
Geology by James Park, F.G.S.

— Reference to Geological Colours and Signs —

MIOCENE (LOWER OAMARUIAN) ...... Conglomerates, sandstones, shales, blue clays, limestones and fireclays with seams of brown coal.

PERMO-CARBONIFEROUS (?) (MAITAI SERIES) ...... Sandstones, greywacke and argillites with bands of aphanitic breccia and red jasperoid argillite

Dyke of Augite-Porphyrite ....

Coal-outcrops ....

Miocene limestone .... Lste

Area of burnt coal ....

Drawn by G. E. Harris, 1921.

CHAPTER IX.

LIMESTONES, CLAYS, AND CEMENTS.

LIMESTONES.

THE Tertiary limestones overlying the coal-measures form high ridges with steep escarpments at Clifden, and between the village of Feldwick and Sharpridge to the north. The limestones of the same age at Helmet Hill, Digger's Hill, and elsewhere in the Waiau Valley are generally too impure to be of economic importance.

The Clifden limestone is of vast extent and of good, though not high, grade. It is easily accessible, and is situated not more than eight or ten miles from the rail-head at Tuatapere. At the present time it is being mined and pulverized for agricultural purposes at a quarry less than a mile from Clifden.

Samples selected at various places between Clifden Bridge and the Waiau Caves show that the limestone varies considerably in quality, both vertically and horizontally. The calcium-carbonate content ranges from 75·6 to 93·5 per cent. An average sample of the pulverized limestone, representing the average of a face 40 ft. high, was analysed at the Dominion Laboratory with the following results :—

Analysis of Pulverized Limestone from Clifden Quarry.

Silica (SiO_2)	3·40
Alumina (Al_2O_3)	0·66
Ferric oxide (Fe_2O_3)	1·31
Calcium carbonate ($CaCO_3$) (estimated by difference)	93·53
Magnesia (MgO)	0·97
Phosphoric anhydride (P_2O_5)	0·10
	100·00

The analyses of a series of samples obtained from the limestone ridge on which Trig. G is situated are given below. No. 1 is from the rock shelter on the right side of the road, half a mile from Clifden Bridge, and Nos. 2 to 8 from the ridge leading up to Trig. G.

	(1.)	(2.)	(3.)	(4.)	(5.)	(6.)	(7.)	(8.)
Silica	12·8	9·8	6·6	5·8	6·5	3·2	6·7	9·1
Alumina	7·3	4·7	3·5	1·8	2·4	1·8	2·6	4·6
Ferric oxide	2·4	2·0	1·4	0·5	1·2	1·1	1·0	1·6
Calcium carbonate	75·6	81·6	86·2	89·4	87·4	91·4	87·4	82·4
Magnesium carbonate	0·9	1·1	1·3	1·4	1·3	1·4	1·2	1·0
Organic matter and water	1·0	0·8	1·0	1·1	1·2	1·1	1·1	1·3
	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0

It is difficult to obtain samples by surface chipping that will represent the average composition of the rock when broken in bulk. Probably the sample of pulverized limestone approximates the average composition more nearly than the mean of the eight samples quoted above.

In a valuable memoir on "The Limestone and Phosphate Resources of New Zealand" Mr. P. G. Morgan,* Director of the Geological Survey, quotes from the *Official Record of the New Zealand and South Seas Exhibition*, Dunedin, 1890–91, the results of nine analyses of limestones from Merrivale that were exhibited as building-stones. As the Merrivale Settlement includes the limestone area at Clifden, the samples were doubtless obtained in that neighbourhood. The calcium-carbonate content of these samples was as follows: No. 1, 89·0 per cent.; No. 2, 87·0; No. 3, 86·0; No. 4, 74·0; No. 5, 95·0; No. 6, 91·0; No. 7, 74·5; No. 8, 81·0; No. 9, 92·2.

There is a large body of limestone at Sharpridge, but the average calcium-carbonate content is lower than that of the Clifden limestone.

A sample of limestone collected by Mr. R. Donnelly, of Wairio, from the small patch of limestone at the base of Twinlaw Peak, and about three miles from Moretown, was analysed by the Dominion Analyst with the following results:—

Silica (SiO_2)	0·90
Alumina (Al_2O_3)	0·50
Iron oxide (Fe_2O_3)	0·20
Magnesia (MgO)	0·72
Phosphorus anhydride (P_2O_5)	0·20
Calcium carbonate ($CaCO_3$) (by difference)	97·48
	100·00

CLAYS.

Classification of Clays.

Geologically, clays may be classified according to their origin or chemical composition; technologically, they are grouped according to their uses. Genetically, all clays fall into two great groups: (1) Residual clays; (2) transported clays.

Residual clays are those formed by the decomposition of rocks in place. The decomposition may be brought about by gases, steam, or heated waters given off by igneous intrusions, or by rain, carbonic-acid gas, frost, or changing temperature, that, singly or together, crumble and disintegrate the surfaces of rocks exposed to the atmosphere.

Clays of this type are formed from the decomposition of all kinds of igneous and sedimentary rocks containing silicate minerals, and in consequence show a wide range in composition and physical properties.

The kaolin, or china, white-burning clays are derived from the decomposition of granites, pegmatites, quartz-porphyries, and gneisses in which the feldspar constituent contains practically no iron, and is easily broken up by steam or waters charged with carbonic acid. The residual clays of basic and semi-basic igneous rocks are usually red, this arising from the decomposition of the ferro-magnesian minerals, which play a more important part in the constitution of these rocks than of granite and other acidic rocks.

Transported clays consist of residual clays that have been transported by water, or of the finer clayey decomposition products that have been washed off the rock-surfaces by rain as fast as they were formed. Many of the younger Mesozoic and Cainozoic clays are composed of materials derived from the denudation of pre-existing sedimentary rocks of an argillaceous character.

As a consequence of the manner in which they are formed, both residual and transported clays are as varied in composition as the rocks from which they are derived.

Residual clays accumulate in place in close association with the parent rock. They may vary from a few inches to 30 ft. or more in thickness, and may form irregular deposits of large size; but generally the portions of economic value are of small extent and variable composition.

* P. G. Morgan and others: *Geol. Bull. No. 22 (N.S.)*, Part I, Limestone, pp. 279–80, 1919.

Transported clays, according to their mode of formation, may be—

(1) *Flood-plain clays*, deposited by rivers during seasonal inundations. They are usually sandy and of small extent.

(2) *Lacustrine clays*, deposited in lakes or shallow fresh-water lagoons. Many fireclays and shales were formed on the floor and shores of lakes.

(3) *Estuarine and deltaic clays*, generally impure and sandy, or interbedded with sandy layers.

(4) *Marine clays*, often of great extent and thickness, and usually of finer texture and more uniform composition than deltaic or lacustrine clays. When calcareous, marine clays pass into marls.

If classified according to their industrial uses, clays may be subdivided into six groups :—

(1) Porcelain and whiteware clays : Kaolin, china-clay, ball-clay.
(2) Refractory clays : Fireclay, siliceous shale, stoneware-clay.
(3) Pottery clays.
(4) Vitrifying-clays.
(5) Brick-clays.
(6) Clays for cement-making.

The whitestone clays consist essentially of hydrous aluminium silicate derived from the decomposition of the feldspar constituent of acidic igneous and metamorphic rocks. Industrially they are called "high-grade" clays. Their value lies in their white-burning property and the low content of iron, lime, magnesia, and alkalies, or other fluxing-minerals. The relatively high proportion of lime and alkalies in some kaolins usually arises from the presence of undecomposed feldspar.

Of fireclays, the best are those which contain the lowest percentage of fluxing-minerals, as iron, lime, magnesia, and alkalies, and the smallest amount of sand or free silica—that is, silica not in combination with the alumina. The highest refractory index is obtained when the proportion of free silica to the aluminium silicate ranges from 1 to 6·5 or 8.

Stoneware-clay is a refractory or semi-refractory clay of low grade, but possessing toughness and a high degree of plasticity. The sand must exist as very fine grains.

Pottery-clays are low-grade plastic clays used for the manufacture of products for domestic and ornamental use, ranging from flower-pots to delicately formed vases.

Vitrifying-clays are high in fluxes. They are used for the production of paving-tiles, paving-bricks, and sewer-pipes. A high iron content aids the formation of the salt-glaze with which pipes are covered.

Brick-clays are usually low-grade red-burning clays that are capable of being easily moulded, and that burn hard at a relatively low temperature without undue shrinkage or warping. In a good brick-clay the physical properties are of greater importance than the chemical composition ; hence the value of a clay for brickmaking can only be determined by actual experimental tests.

Clays for the manufacture of artificial Portland cement contain a high proportion of silica, and not over 15 per cent. of iron oxides.

The approximate range of certain constituents in industrial clays is shown below :—

Percentage Range of Clay Constituents.

—	Fireclays.		Pottery-clay.		Brick-clay.		Vitreous Clays.		Cement-clays.	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Silica	97	35	86	45	90	34	70	55	60	40
Alumina	40	2	35	14	44	10	25	11	20	10
Iron oxide	3	0	7	0	32	0	9	2	8	4
Lime	2	0	10	0	15	0	3	0	20	2
Magnesia	1	0	5	0	7	0	3	0	5	1
Alkalies	3	0	7	0	15	0	4	0	3	0·5

A pure kaolin clay consists of the three essential constituents silica, alumina, and water, which occur in chemical combination as the hydrous aluminium silicate called "kaolinite." Kaolinite in excessively fine particles when mixed with water forms what is technologically called "plastic kaolin." In all industrial clays kaolinite in finely divided form is the essential constituent; and it is owing to the colloidal properties of the contained plastic kaolin that industrial clays derive their plasticity and adhesive strength. The free silica (or sand), iron oxide, lime, magnesia, and alkalies usually present in low-grade clays are merely accidental impurities that vary in amount according to the character of the parent rock and conditions of deposition. For certain industrial uses an excess of sand is not always injurious. In the case of brick-clays deficient in free silica it is necessary to add a certain amount of sand in order that the bricks may be able to retain their form during the process of burning. And in the case of vitreous clays, the iron, lime, magnesia, and alkalies serve a useful purpose.

Residual Clays.

In recently glaciated regions residual clays are, as a rule, absent, or but poorly represented. The clays of this type that existed before the Pleistocene period were easily removed by the advancing ice-sheet; and in the short interval that has elapsed since the retreat of the ice fresh depos ts have not had sufficient time to accumulate.

In the upper and middle parts of the Waiau basin residual clays are practically non-existent. Isolated patches begin to appear near the junction of the Wairaki and Waiau rivers and in the lower part of the Lillburn Valley, but they are of small extent. They represent the weathered parts of the Upper Miocene (Awamoan) clays that lie in the Clifden syncline. Near the junction of the main road to Otautau and the branch road going to Merrivale, a few hundred yards from the Clifden limestone quarry, there occurs a large deposit of residual clay resting on the outcrop of the clayey and sandy beds that underlie the limestone. Dr. Maclaurin, the Dominion Analyst, has furnished the following analysis on an air-dried sample of this clay (No. 776/4) collected in the road-cutting opposite Mr. King's farm:—

Silica (SiO_2)	60·83
Titanium oxide (TiO_2)	0·88
Alumina (Al_2O_3)	14·14
Ferric oxide (Fe_2O_3)	6·81
Lime (CaO)	1·95
Magnesia (MgO)	1·95
Potash (K_2O)	1·77
Soda (Na_2O)	2·23
Water lost at 100° C.	4·73
Combined water and organic matter	4·67
Carbon dioxide (CO_2)	Nil
	99·96

Transported Clays.

Transported clays, as members of the Middle Tertiary series, cover extensive areas in western Southland. According to their origin they may be classified as (1) marine clays, (2) marine marls and deltaic clays. The former comprise the uppermost beds of the Tertiary series. They overlie the Clifden limestone, and are strongly represented in the Clifden–Lillburn basin. The marine and deltaic clays underlie the limestone, and are the beds with which the Nightcaps Wairio, Ohai, and Waiau coals are associated. They form thick beds at Blue Cliff, Tuatapere, Lower Orawia, Sunnyside, Blackmount, Ohai, Wairio, and Nightcaps, and are the dominant members of the coal-measures.

Marly Clays of the Sunnyside–Blackmount Basin, Waiau Valley.

A great thickness of pale-blue marly clays is exposed along the course of the Waiau River above Sunnyside homestead, at Blackmount homestead. From the Waiau River these clays extend eastward to the foot of the Takitimu Mountains. There are many fine exposures in the branches of Waikoe and Makarewa streams, especially to the east side of the main Manapouri Road. Altogether these clays occupy many square miles in the Sunnyside-Blackmount area.

The analyses of two samples of these clays by Dr. Maclaurin, Dominion Analyst, are given below. Sample No. 7 is from the west bank of the Waiau River, about a mile above Sunnyside homestead; and sample No. 8 from the west bank of Ligar Creek, a quarter of a mile above Blackmount homestead. Two analyses of the Burnside marl, A and B, used by the Milburn Lime and Cement Company (Limited) for cement-manufacture are given for comparative purposes.

	No. 776/7.	No. 776/8.	A.	B.
Silica (SiO_2)	40·85	52·06	46·28	49·29
Titanium oxide (TiO_2)	0·72	0·69	..	..
Alumina (Al_2O_3)	13·32	11·30	8·70	11·77
Ferric oxide (Fe_2O_3)	5·42	4·68	3·92	4·16
Lime (CaO)	15·11	9·90	19·04	16·32
Magnesia (MgO)	2·15	1·81	1·65	1·49
Potash (K_2O)	1·60	1·80	3·11	2·74
Soda (Na_2O)	0·45	0·76		
Water lost at 100° C.	5·38	5·95	4·53	3·96
Combined water and organic matter	4·85	4·12	..	..
Carbon dioxide (CO_2)	10·59	6·72	12·77	9·80
	100·44	99·79	100·00	99·53

The Sunnyside and Blackmount marly clays, being high in lime and low in both magnesia and alkalies, are admirably suited for the manufacture of Portland cement.

Clays of Clifden–Lillburn Basin.

These clays belong to the Awamoan stage of the Tertiary series. They occupy many square miles in the floor of the Lillburn and Waiau valleys, but are generally concealed by Recent gravels. They are well exposed near Mr. Struan Gardner's homestead in the Lillburn Valley and at the mouth of the Wairaki River. At Lake Hauroto they are obscured by glacial débris. Sample No. 5, from near Struan Gardner's, in the Lillburn Valley, and No. 6, from the eastern shore of Lake Hauroto, were analysed in the Dominion Laboratory, with the following results:—

	No. 776/5.	No. 776/6.
Silica (SiO_2)	55·73	57·62
Titanium oxide (TiO_2)	Undet.	0·86
Alumina (Al_2O_3)	22·84	12·33
Ferric oxide (Fe_2O_3)	5·04	7·60
Lime (CaO)	3·80	1·50
Magnesia (MgO)	0·17	2·27
Potash (K_2O)	1·76	2·02
Soda (Na_2O)	2·84	1·15
Water lost at 100° C.	2·43	8·73
Combined water and organic matter	5·37	5·64
Carbon dioxide (CO_2)	Undet.	Undet.
	99·98	99·72

No. 776/5, from the Lillburn, is high in silica and low in magnesia and alkalies, and therefore suitable for the manufacture of Portland cement.

The clays of the coal-measures occupy a large area between Tuatapere and the junction of the Orawia River. Dr. Maclaurin's analysis, quoted below, shows that the ratio of the combined alumina and ferric oxide to the silica is higher than desirable in a clay for the manufacture of Portland cement.

Clay from East Bank of Waiau River, Tuatapere (No. 776/3).

Silica (SiO_2)	46·99
Titanium oxide (TiO_2)	1·05
Alumina (Al_2O_3)	17·31
Ferric oxide (Fe_2O_3)	10·76
Lime (CaO)	2·19
Magnesia (MgO)	1·96
Potash (K_2O)	1·62
Soda (Na_2O)	1·07
Water lost at 100° C.	8·68
Combined water and organic matter	7·36
Carbon dioxide (CO_2)	1·33
	100·32

CLAYS OF MARAROA BASIN.

Along the foot of the Takitimu Mountains the Middle Tertiary coals are overlain by a bed of clay, usually crushed and slickensided. This clay occurs in isolated patches that are mostly of small extent. A sample (No. 776/9), collected from the bed overlying the "rosin seam" at Princhester Creek coal-mine, showed the following composition :—

Analysis of Princhester Clay, by Dr. Maclaurin.

Silica (SiO_2)	47·46
Titanium oxide (TiO_2)	1·24
Alumina (Al_2O_3)	22·38
Ferric oxide (Fe_2O_3)	10·51
Lime (CaO)	0·74
Magnesia (MgO)	0·97
Potash (K_2O)	0·82
Soda (Na_2O)	..
Water lost at 100° C.	2·88
Combined water and organic matter	13·44
Carbon dioxide (CO_2)	Undet.
	100·44

CLAYS OF WAIRIO–NIGHTCAPS AREA.

A great thickness of clays overlies the coal-seams at Nightcaps, Moretown, and Quested's. At Quested's the "rosin seam" is overlain by a tough plastic clay of good quality.

Analysis of Quested's Fireclay, by Dr. Maclaurin (No. 776/2).

Silica (SiO_2)	52·11
Titanium oxide (TiO_2)	1·23
Alumina (Al_2O_3)	24·78
Ferric oxide (Fe_2O_3)	2·76
Lime (CaO)	0·45
Magnesia (MgO)	0·80
Potash (K_2O)	1·42
Soda (Na_2O)	0·25
Water lost at 100° C.	4·28
Combined water and organic matter	12·49
Carbon dioxide (CO_2)	Undet.
	100·57

Reporting on the high-temperature tests made with this clay in the Dominion Laboratory Dr. Maclaurin says that it formed "at 1060° C. a fairly hard cream-coloured brick, and at 1170° C. a very hard cream-coloured brick with stoneware body." This clay should prove of considerable commercial value for brick and tile making.

The upper members of the coal-measures at Wairio and Nightcaps are crumbling dark-blue clays, which are well exposed in the railway-cuttings about a mile from Moretown and in the deep railway-cutting a mile from Nightcaps Railway-station. These clays appear to occur in the same horizon as the marly clays already referred to in the Sunnyside–Blackmount basin, but are distinguished from these by their lower lime content. A sample from the railway-cutting a mile from Moretown showed the following composition :—

Analysis of Wairio Clay, by Dr. Maclaurin (No. 776/1).

Silica (SiO_2)	48·49
Titanium oxide (TiO_2)	0·96
Alumina (Al_2O_3)	20·69
Ferric oxide (Fe_2O_3)	8·83
Lime (CaO)	0·70
Magnesia (MgO)	1·48
Potash (K_2O)	1·51
Soda (Na_2O)	0·22
Water lost at 100° C.	5·43
Combined water and organic matter	10·97
Carbon dioxide (CO_2)	Undet.
	99·31

This clay could be used for the manufacture of Portland cement, but it would be inferior to No. 776/5 from Struan Gardner's property in the Lillburn Valley, No. 776/6 from Lake Hauroto, and much inferior to No. 776/7 from Sunnyside, and No. 776/8 from Ligar Creek, near Blackmount homestead, or the similar clays between Taylor's Creek and the sources of Grassy Creek, in the same area.

Proportion of Clay Substance.

The proportion of hydrated aluminium silicate, usually called "clay substance" or "clay base," contained in a clay exercises a powerful influence on the technological purposes for which the clay may be used. In his valuable report on the clay-samples Nos. 776 (1 to 9), the analyses of which have been given in the preceding pages, Dr. Maclaurin says that theoretically these clays, if completely dried at 100° C., would have the following composition :—

——	776/1	776/2	776/3	776/4	776/5	776/6	776/7	776/8	776/9
Quartz	20·60	19·08	19·99	32·59	13·71	36·83	20·34	33·27	24·29
Feldspar	11·74	10·90	20·39	30·83	35·31	23·84	14·01	18·23	4·98
Clay substance and combined water	67·66	70·02	56·32	36·58	50·98	39·33	40·35	32·20	70·73
Calcium carbonate ..	..	..	3·30	Nil	..	..	25·30	16·30	..
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

In ordinary brick which is burned at a relatively low temperature a large percentage of sand is advantageous, as it prevents shrinkage and warping; but at high temperatures free silica acts as a flux, and experience has shown that the clays with the smallest quantity of uncombined silica are the most refractory.

High-temperature Tests.

Dr. Maclaurin's report on the high-temperature tests made under his direction in the Dominion Laboratory is as follows :—

"Small bricks and tiles made from the clays were dried at 100° C. and burned at temperatures of 1060° C. and 1170° C. All the clays mould well, and, with the exception of No. 776/4, are of high plasticity."

High-temperature Tests.

No.	Shrinkage at 100° C.	Shrinkage at 1060° C.	Shrinkage at 1170° C.	Nature of Bricks produced.
776	Per Cent.	Per Cent.	Per Cent.	
1	7·8	14·1	. .	At 1060° C., a pale yellowish-red brick, hard but somewhat cracked; at 1170° C., a dark-red brick cracked, swollen, and fused at centre.
2	6·25	14·1	14·0	At 1060° C., a fairly hard cream-coloured brick; at 1170° C., a very hard cream-coloured brick with stoneware body.
3	8·4	15·6	. .	At 1060° C., a red brick, cracked, swollen, and fused in parts to a vesicular slag.
4	6·25	15·6	. .	At 1060° C., a dark-red very hard brick with stoneware body.
5	5·0	14·1	. .	At 1060° C., a brownish-red brick, swollen in centre, and partly fused to a vesicular slag.
6	5·0	. .	. .	At 1060° C., a brownish-red brick, broken, swollen, and partly fused.
7	5·6	14·1	. .	At 1060° C., a cream-coloured brick, warped and cracked. Portion of another brick completely fused.
8	6·25	7·8	. .	At 1060° C., a very pale-red rather soft brick; at 1170° C., the clay fuses completely to a dark translucent slag.
9	6·25	11·9	14·1	At 1060° C., a very pale-red rather soft brick; at 1170° C., a dark-red very hard brick, somewhat cracked.

776/1 (sample No. 1), clay from railway-cutting half-mile on Wairio side of Moretown.
776/2 (sample No. 2), clay overlying "rosin seam," Quested's.
776/3 (sample No. 3), clay from east bank of Waiau River, near bridge, Tuatapere.
776/4 (sample No. 4), residual clay from road-cutting near King's farm, opposite limestone quarry, near Clifden.
776/5 (sample No. 5), marine blue clay, Struan Gardner's, Lillburn Valley, Waiau.
776/6 (sample No. 6), marine blue clay from eastern shore of Lake Hauroto.
776/7 (sample No. 7), blue marine clay from west bank of Waiau River a mile above Sunnyside homestead.
776/8 (sample No. 8), blue marine clay from west bank of Ligar Creek, near Blackmount homestead, Waiau Valley.
776/9 (sample No. 9), clay overlying "rosin seam" at Princhester Creek coal-mine, at north end of Takitimu Mountains.

Reporting on these results Dr. Maclaurin says: "It will be seen that Nos. 2, 4, 8, and 9 are the only clays likely to prove of commercial value, and of these No. 8 would require most careful regulation of the temperature in burning. The very low fusing-point and short vitrification range of Nos. 8 and 9 are no doubt influenced by the high lime content. The fusing, swelling, and cracking shown by Nos. 1, 3, 5, and 6 seem to be connected with the large amount of iron in these clays, associated with fairly high percentages of other fluxing-materials. It may be noted also that while these clays are 'blue clays,' No. 4, which is a clay of similar composition, but does not exhibit these defects, is a yellow one. No. 9, though it contains much iron, has comparatively small amounts of other fluxing-materials."

Birchwood Clays.

Blue marine marly clays of great thickness occupy a large area at Birchwood in the Ohai Valley. These clays lie below the limestone, and overlie the coal-measures. In character and composition they resemble the blue clays at Blackmount and Sunnyside. The analysis quoted below shows that the Birchwood clays possess the constituents required in a clay for the manufacture of a first-class Portland cement.

Analysis of Birchwood Clay, by Dr. Maclaurin.

Silica (SiO_2)	45·79
Titanium oxide (TiO_2)	0·71
Alumina (Al_2O_3)	11·52
Ferric oxide (Fe_2O_3)	5·17
Lime (CaO)	12·70
Magnesia (MgO)	1·57
Potash (K_2O)	1·69
Soda (Na_2O)	1·04
Water lost at 100° C.	7·75
Carbon dioxide (CO_2)	9·74
Combined water and organic matter	2·74
	100·42

The analysis was made on an air-dried sample. Dr. Maclaurin reports that if the clay were dried at 100° C. its composition, calculated from the analysis, would be as follows:—

Quartz	32·3
Feldspar	20·3
Calcium carbonate	24·0
Clay substance	23·4

In reference to temperature tests made in the Dominion Laboratory he reports that small bricks prepared from the clay were dried at 100° C. and baked at 1040° C., and were badly cracked and had commenced to swell at the centre and to vitrify. Small tiles baked at a somewhat lower temperature were pink-coloured and of moderate hardness. They showed the following shrinkage: At 100° C., 8·5 per cent.; on burning, 9·4 per cent.

The Birchwood clays contain too high a proportion of fluxing-constituents for the manufacture of firebrick or other refractory products; but with careful regulation of temperature they could be used for the manufacture of red roofing-tiles and drain-pipes. The ratio of the alumina and iron oxide to the silica is approximately 1 to 3. This relationship and the high lime and low magnesia content constitute an ideal clay for the manufacture of Portland cement.

CEMENTS.

Chemically considered, cement is a complex silicate of lime, magnesia, and iron of variable composition. According to their origin, cements are classified as (1) artificial, (2) natural.

Of artificial cements the best-known kinds are Portland cement and Roman cement. They are manufactured by calcining an intimate mixture of limestone and clay, and afterwards grinding the resulting clinker to a fine powder. Generally, a mixture of 75 per cent. of high-grade limestone and 25 per cent. of clay will produce a good Portland cement.

In England the best Roman cements are made from the following proportions of limestone and clay: Limestone, 49 to 66 per cent.; clay, 47 to 32 per cent.

Among engineers the limits of a good Portland cement are—

	Per Cent.
Silica (SiO_2)	19·00 to 26·00
Alumina (Al_2O_3)	4·00 to 10·00
Ferric oxide (Fe_2O_3)	2·00 to 4·00
Lime (CaO)	57·00 to 66·00
Magnesia (MgO)	0·00 to 4·00
Sulphuric anhydride	0·00 to 2·00

To produce slow-setting cement the American practice is to add gypsum (calcium sulphate) up to 2 per cent. The lime, silica, and iron play an important part in the formation of a good cement. Magnesia alone is an impurity, performing no useful function, and becoming dangerous if present in too large proportions, as it needs a much higher temperature than lime to enable it to combine with silica, and hence, if present in excess, a portion is usually left uncombined or only loosely combined.

Most cements contain potash and soda, collectively called "alkalies"; but the amount is small, and the effect so unimportant that they are not as a rule estimated separately. Marine clays and marls that contain streaks, bands, or nodules of glauconitic material may run high in potash, and should not be used in cement-manufacture, as the potash, being a powerful flux, soon destroys the firebrick lining of the revolving calcining-furnace.

According to Le Chatelier,* the minimum proportion of lime in a true Portland cement should not be less than $\frac{CaO + MgO}{SiO_2 + Al_2O_3} = 3$, nor the maximum greater than $\frac{CaO + MgO}{SiO_2 + Al_2O_3 + Fe_2O_3} = 3$.

In the construction of these formulæ Le Chatelier assumed that not more than three equivalents of lime or magnesia can enter into chemical combination with silica and alumina. British cement-manufacturers adhere generally to the proportions of lime indicated by Le Chatelier's formulæ.

Natural cements are those produced from rock containing the requisite proportions of lime and clay. The finest natural cement in the market is that produced at Grenoble, in France, where a bed of argillaceous limestone (hydraulic limestone) 15 ft. in thickness occurs interbedded in a compact limestone.

The composition of the argillaceous limestone is—

	Per Cent.
Silica	13·40 to 17·37
Alumina	6·20 to 12·37
Iron oxides	3·50 to 12·37
Calcium carbonate	66·50 to 64·75
Magnesium carbonate	6·00 to traces
Water and loss	4·40 to 5·50

After calcining, the resulting cement has the following composition:—

	Per Cent.
Silica	27·30 to 26·30
Alumina	9·30 to 12·70
Lime	50·80 to 55·00
Magnesia	3·00 to 0·00

This cement is quick-setting, taking from eight to sixteen minutes to set. Mixed with three parts of sand it can bear a weight of 113 lb. per square inch after being set for two hours.

Large deposits of argillaceous limestone of Middle Tertiary age occur in north Canterbury, at Amuri Bluff, in the Clarence Valley, Kaikoura Peninsula, and Cape Campbell areas, in the South Island; and on the east coast of Wellington and north Auckland, in the North Island. No argillaceous limestone suitable for the manufacture of Portland cement occurs in Otago or Southland.

The Economics of Cement-manufacture.

The raw materials required for the manufacture of Portland cement are limestone of good grade and a siliceous clay. Besides these, coal is required for drying and calcining. Generally, the raw materials are mixed in the proportion of 50 tons of clay to 100 tons of limestone. In modern well-equipped plants about 100 tons of coal are required for every 100 tons of limestone in the cement mixture. Approximately, the proportions are—Limestone, 6 tons; clay, 3 tons; coal, 6 tons.

Economically considered, the best place for the manufacture of cement is where the limestone, clay, and coal occur together; and if these three occur at a place centrally situated in respect of the means of distribution we get the theoretically ideal condition.

Limestone and clay occur in the Clifden district, but there is no coal; limestone occurs in the Winton - Forest Hill district, but there is no clay or coal. And here it may be mentioned that, though bituminous coals are in common use for calcination, low-grade lignitic fuels cannot be used economically for this purpose. Clay and coal occur in abundance at Wairio and Nightcaps, but there is no limestone nearer than the base of Twinlaw Peak, some three miles from Moretown.

* *Annales des Mines*, p. 345, 1887.

The local brown coals could be used for power purposes in connection with the manufacture of Portland cement, but bituminous coal for clinkering would have to be obtained from the West Coast or New South Wales.

If we consider the immediate needs of Southland in connection with the great hydro-electric scheme now under way, Clifden at once presents itself as the best place for the manufacture of cement; but if we look to the future and more permanent needs of Southland, the Makarewa Junction seems to be the most suitable and convenient site for the central works. This place is already connected by railway with the limestone deposits in the Winton – Forest Hill district, distant some eighteen miles, and by railway with Wairio and Nightcaps, distant some forty-five miles, all on the down grade and in favour of the load. Against the railage charges would be set off the small transport charge to convey the manufactured cement to Invercargill, which for many years after the completion of the Monowai hydro-electric installation is certain to be the principal market. Moreover, on account of the better conditions of life, the wage charges would be less than in a remote district.

Marly clays in large quantity, and of the best quality for cement-manufacture, occur at Birchwood, in the Ohai Valley; and limestone of high grade is present at the base of Twinlaw Peak. If these places possessed transport facilities the claims of Ohai as the site for the main Southland cement-works would have to be seriously considered. The ultimate selection of the site for the works must rest with those who undertake to finance the undertaking. In its coals, limestones, and clays Southland possesses assets of great value.

BUILDING-STONES.

Certain bands of the Tertiary polyzoan limestone at Clifden are well adapted for building-stone of the softer kind, being little inferior to Oamaru stone except in colour.

Among the harder crystalline rocks, the diorites, diorite-gneisses, and granites of the Clinton River Series, as developed to the west of Lake Monowai, Lake Manapouri, and Lake Te Anau, and at the south end of the Longwood Range, will furnish sound heavy stones in great variety, eminently suited for engineering construction, house-building, and ornamental purposes. Of these stones the most accessible occur on the coast between Jacob's River and Orepuki, and in the neighbourhood of Round Hill. Besides these, the melaphyre at Jacob's Estuary, the basalt at Mount Pleasant in the Pourakino Creek area, and the augite-porphyrite in the Ohai district will be some day sought after as building-stones. Meantime, on account of its accessibility and the ease with which it may be opened up, the norite of Bluff Hill will supply Southland's needs for many years to come.

In the next century Southland will be famous for its building-stones, of which it possesses a larger quantity and greater variety than any other part of New Zealand.

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